BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 27

JOSEPH STANLEY-BROWN, Editor

NEW YORK
PUBLISHED BY THE SOCIETY
1916

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The Maurice Joyce Engraving Company, Washington, D. C.

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(30 plates; 55 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually, in four quarterly parts, a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 700 copies. A small supply of authors' separates of the longer articles is kept for sale by the Secretary at the prices quoted in each volume.

The Bulletin is sold at the uniform price of ten dollars ($10.00) per volume, with a discount of twenty-five (25) per cent to Fellows of the Society, persons residing elsewhere than in North America, and public and institutional libraries; carriage extra. Subscriptions are payable in advance. Regular subscribers within the United States of America and its possessions receive their parts, postage paid, as issued. Forty (40) cents per volume must be added to the subscription price to cover postage to other countries in the Postal Union.

The price of the index to volumes 1-10 is $2.25 and of the index to volumes 11-20 is $3.50; carriage extra. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.
Vol. 1, 1889	593 + xii	13	51
Vol. 2, 1890	622 + xiv	23	63
Vol. 3, 1891	541 + xi	17	72
Vol. 4, 1892	458 + xi	10	55
Vol. 5, 1893	655 + xii	21	43
Vol. 6, 1894	528 + x	27	40
Vol. 7, 1895	558 + x	24	61
Vol. 8, 1896	446 + x	51	29
Vol. 9, 1897	460 + x	29	49
Vol. 10, 1898	534 + xii	54	83
Index to volumes 1–10	209	..	..
Vol. 11, 1899	651 + xii	58	37
Vol. 12, 1900	538 + xii	45	28
Vol. 13, 1901	583 + xii	58	47
Vol. 14, 1902	609 + xii	65	43
Vol. 15, 1903	636 + x	59	16
Vol. 16, 1904	636 + xii	94	74
Vol. 17, 1905	785 + xiv	84	96
Vol. 18, 1906	717 + xii	74	59
Vol. 19, 1907	617 + x	41	31
Vol. 20, 1908	749 + xiv	111	35
Index to volumes 11–20	422	..	..
Vol. 21, 1909	823 + xvi	54	109
Vol. 22, 1910	747 + xii	31	66
Vol. 23, 1911	758 + xvi	43	44
Vol. 24, 1912	737 + xviii	36	60
Vol. 25, 1913	802 + xviii	28	47
Vol. 26, 1914	504 + xxi	27	41
Vol. 27, 1915	739 + xviii	30	55

PARTS OF VOLUME 27

	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Number 1	1–192	1– 9	9	$2.45	$3.50
Number 2	193–450	10–18	21	3.00	4.50
Number 3	451–554	19–21	8	1.20	1.80
Number 4 *	555–739	22–30	17	2.45	3.50

REPRINTS FROM VOLUME 27

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Proceedings of the Twenty-eighth Annual Meeting of the Geological Society of America, held at Washington, D. C., December 28, 29, and 30, 1915. CHARLES P. BERKEY, *Secretary pro tem*	1–138	1– 9	1– 9	$1.70	$2.50
Proceedings of the Seventh Annual Meeting of the Paleontological Society, held at Washington, D. C., December 29, 30, and 31, 1915. R. S. BASSLER, *Secretary* †	139–174	....	....	.45	.70
Dry land in geology. A. P. COLEMAN	175–192	....	....	.25	.35
Hypersthene syenite and related rocks of the Blue Ridge region, Virginia. T. L. WATSON and J. H. CLINE	193–234	....	1	.55	.80
Pleistocene uplift of New York and adjacent territory. H. L. FAIRCHILD	235–262	10–12	....	.50	.75
Glaciation in the White Mountains of New Hampshire. J. W. GOLDTHWAIT	263–294	13	1	.45	.65
Pleistocene drainage changes in western North Dakota. A. G. LEONARD	295–304	14	1	.15	.20
Alexandrian rocks of northeastern Illinois and eastern Wisconsin. T. E. SAVAGE †	305–324	15–17	....	.35	.50
Petrography of the Pacific Islands. R. A. DALY	325–344	....	....	.30	.45
Dominantly fluviatile origin under seasonal rainfall of the Old Red Sandstone. J. BARRELL	345–386	....	1	.55	.80
Influence of Silurian-Devonian climates on the rise of air-breathing vertebrates. J. BARRELL	387–436	....	1– 2	.70	1.00
Crystalline marbles of Alabama. W. F. PROUTY	437–450	18	1–15	.20	.30
Correlation by displacements of the strand-line and the function and proper use of fossils in correlation. E. O. ULRICH †	451–490	....	....	.55	.80
Correlation and chronology in geology on the basis of paleogeography. C. SCHUCHERT †	491–514	19–21	1– 7	.40	.55

* Preliminary pages and index are distributed with number 4.

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Methods of correlation by fossil vertebrates. W. D. Matthew †	515–524	....	....	$0.15	$0.20
Principles governing the use of fossil plants in geologic correlation. F. H Knowlton †	525–530	....	....	.10	.15
Silurian formations of southeastern New York, New Jersey, and Pennsylvania. C. Schuchert †	531–554	....	1	.35	.50
Comparison of American and European Lower Ordovicic formations. A. W. Grabau †	555–622	....	1–10	.95	1.40
Triassic igneous rocks in the vicinity of Gettysburg, Pennsylvania. G. W. Stose and J. V. Lewis	623–644	....	1– 2	.30	.45
Glacial lakes and other glacial features of the central Adirondacks. H. L. Alling	645–672	22–24	1– 2	.40	.60
Cretaceous of Alberta, Canada. J. H. Sinclair	673–684	....	1– 2	.20	.25
Triassic rocks of Alaska. G. C. Martin	685–718	25–30	1	.45	.70

†Under the brochure heading is printed Proceedings of the Paleontological Society.

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

The following separates of parts of volume 27 have been issued:

Regular Editions

Pages	175–192,		70 copies.	March	31, 1916.
"	193–234,		140 "	June	1, 1916.
"	235–262,	plates 10–12,	140 "	"	1, 1916.
"	263–294,	plate 13,	190 "	"	1, 1916.
"	295–304,	" 14,	240 "	"	1, 1916.
"	305–324,*†	plates 15–17,	265 "	"	3, 1916.
"	325–344,		540 "	"	3, 1916.
"	345–386,		140 "	"	5, 1916.
"	387–436,		340 "	"	7, 1916.
"	437–450,	plate 18,	90 "	"	17, 1916.
"	451–490,*†		390 "	"	23, 1916.
"	491–514,*†	plate 19,	540 "	September	1, 1916.
"	515–524,*†		290 "	"	1, 1916.
"	525–530,*†		190 "	"	1, 1916.
"	531–554,*†	plates 20–21,	490 "	"	13, 1916.
"	555–622,*†		490 "	November	29, 1916.
"	623–644,		340 "	"	30, 1916.
"	645–672,	plates 22–24,	90 "	"	30, 1916.
"	673–684,		65 "	December	9, 1916.
"	685–718,	plates 25–30,	190 "	"	11, 1916.

Special Editions ‡

Pages	12– 15,	plate 1,	40 copies.	March	30, 1916.
"	15– 21,	" 2,	190 "	"	30, 1916.
"	22– 35,	" 3,	40 "	"	30, 1916.
"	35– 37,	" 4,	40 "	"	30, 1916.
"	37– 38,	" 5,	40 "	"	30, 1916.
"	41– 45,		40 "	"	30, 1916.
"	51– 55,	" 6,	140 "	"	30, 1916.
"	72– 77,	plates 7–9,	90 "	"	30, 1916.
"	86– 88,		90 "	"	30, 1916.
"	89– 92,		540 "	"	30, 1916.
"	93–100,		1,040 "	"	30, 1916.
"	104–105,		140 "	"	30, 1916.
"	112–113,		140 "	"	30, 1916.
"	127–138,		90 "	"	30, 1916.
"	139–174,		165 "	"	31, 1916.

* Bearing on the cover
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.
[Reprinted from the Bulletin of the Geological Society of America, vol. ——, pp.— pls. ——, (Date)].

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

‡ Bearing imprint [From Bull. Geol. Soc. Am., Vol. 27, 1915].

CORRECTIONS AND INSERTIONS

All contributors to volume 27 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 19, line 15 from top; *for* "gift" *read* grit
" 21, line 12 from top; *for* "papers" *read* pages
" 21, lines 15 and 17 from top; *for* "Boletino" *read* Boletim
" 93, line 6 from bottom; *for* "Keweenewan" *read* Cretaceous
" 99, line 7 from bottom; *for* "monoclinic" *read* monoclinal
" 100, line 10 from bottom; *for* "first" *read* last
" 114, line 13 from top; *for* "R. B. Woodworth" *read* J. B. Woodworth
" 174, line 13 from top; *for* "Dickenson" *read* Dickerson
" 408, line 1 from bottom; *for* "G. W. Bridge" *read* T. W. Bridge
" 520, line 17 from bottom; *for* "Summary" *read* Conclusions
" 521, page heading; *for* "Summary" *read* Conclusions
" 523, page heading; *for* "Summary" *read* Conclusions
" 524, lines 1 and 8 from bottom; *for* "following" *read* foregoing

BULLETIN

OF THE

Geological Society of America

VOLUME 27 NUMBER 1

MARCH, 1916

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY

MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Washington, D. C., under the Act of Congress of July 16, 1894

PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AME
VOL. 27, PP. 1-138, PLS. 1-9 MARCH 30, 1916

PROCEEDINGS OF THE TWENTY-EIGHTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT WASHINGTON, DISTRICT OF COLUMBIA, DECEMBER 28, 29, AND 30, 1915.

CHARLES P. BERKEY, *Secretary pro tem.*

CONTENTS

Session of Tuesday, December 28

The first general session of the Society was called to order at 9.15 o'clock a. m., Tuesday, December 28, at the George Washington University Medical School, Washington, District of Columbia, by President Coleman.

The report of the Council for the year ending November 30, 1915, was presented as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in twenty-eighth annual meeting assembled:

The regular annual meeting of the Council was held at Philadelphia, Pennsylvania, in connection with the meeting of the Society, December 29-31, 1914.

The details of administration for the twenty-seventh year of the existence of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The proceedings of the annual general meeting of the Society held at Philadelphia, Pennsylvania, December 29-31, 1914, have been recorded in volume 26, pages 1-128; of the Cordilleran Section, pages 129-140, and of the Paleontological Society, pages 141-170, of the Bulletin.

Membership.—During the past year the Society has lost four Fellows[1] by death—Theodore B. Comstock, Orville A. Derby, Joseph A. Holmes, and William J. Sutton. One resignation has become effective. The names of the nineteen Fellows elected at the Philadelphia meeting have been added to the list, all of them having completed their membership according to the rule. The present enrollment of the Society is 376. Six candidates are before the Society for election and several applications are under consideration by the Council.

Distribution of Bulletin.—There have been received during the year 6 new subscriptions to the Bulletin, and 9 subscriptions have been discontinued, making the number of subscribers 115.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 15; sold to Fellows, 1; sent out to supply deficiencies, 1, and delinquents, 5; brochures

[1] Since the meeting the Secretary has received notice of the death of Frank A. Hill.

sent out to supply deficiencies, 8, and delinquents, 44; sold to Fellows, 3; sold to the public, 27.

Bulletin sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

Bulletin Receipts, December 1, 1914–November 30, 1915

	Complete volumes.			Brochures.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1...	....	....	....	....	....	....	....
Volume 2...	....	....	....	....	....	....	....
Volume 3...	....	....	....	....	....	....	....
Volume 4...	....	$7.50	$7.50	....	....	....	$7.50
Volume 5...	....	....	....	....	....	....	....
Volume 6...	....	7.50	7.50	....	....	....	7.50
Volume 7...	....	7.50	7.50	....	....	....	7.50
Volume 8...	....	7.50	7.50	....	....	....	7.50
Volume 9...	....	7.50	7.50	....	....	....	7.50
Volume 10...	....	....	....	....	....	....	....
Volume 11...	....	7.50	7.50	....	....	....	7.50
Volume 12...	....	7.50	7.50	....	....	....	7.50
Volume 13...	....	7.50	7.50	....	$1.20	$1.20	8.70
Volume 14...	....	....	....	....	.90	.90	.90
Volume 15...	....	7.50	7.50	....	1.10	1.10	8.60
Volume 16...	....	7.50	7.50	....	....	....	7.50
Volume 17...	....	....	....	....	1.05	1.05	1.05
Volume 18...	....	....	....	....	1.80	1.80	1.80
Volume 19...	....	....	....	....	2.40	2.40	2.40
Volume 20...	....	7.50	7.50	....	1.40	1.40	8.90
Volume 21...	....	....	....	....	7.15	7.15	7.15
Volume 22...	....	....	....	$4.15	1.80	5.95	5.95
Volume 23...	....	....	....	....	.80	.80	.80
Volume 24...	....	15.00	15.00	1.95	7.55	9.50	24.50
Volume 25...	$7.50	22.50	30.00	....	8.25	8.25	38.25
Volume 26...	....	835.00	835.00	....	4.50	4.50	839.50
Volume 27...	....	60.00	60.00	....	3.75	3.75	63.75
Total....	$7.50	$1,015.00	$1,022.50	$6.10	$43.65	$49.75	$1,072.25
Index 1–10..	....	2.25	2.25	....	....	....	2.25
Index 11–20..	....	3.50	3.50	....	....	....	3.50
Total....	$7.50	$1,020.75	$1,028.25	$6.10	$43.65	$49.75	$1,078.00

Receipts for the fiscal year		$1,078.00
Previously reported		18,300.89
Total receipts to date		$19,378.89
Charged, but not yet received:	On 1911 account	7.50
	On 1915 account	4.90
Total sales to date		$19,391.29

Two subscriptions to volume 26 are still to be paid for.

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURES OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1915

Account of Administration

Note book	$0.20	
Printing (including annual meetings of 1914 and 1915)	94.46	
Messenger service	1.00	
Telegrams	10.45	
Telephone charges	1.03	
Postage	37.36	
Express charges	4.86	
Letter-heads	2.75	
Ribbon for typewriter	.75	
Post-cards	5.50	
Binding three copies of Bulletin	8.00	
Fee to inscribe Society as member of International Engineering Congress	5.00	
Total		$171.36

Account of Bulletin

Express and freight charges	$44.78	
Postage	6.70	
Messenger service	1.55	
Printing	2.00	
Jurat	.25	
Collection charges on checks	1.29	
Wrapping paper	2.73	
Total		$59.30
Total expenditures for the year		$230.66

Respectfully submitted,

CHARLES P. BERKEY,
Secretary pro tem.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending November 30, 1915.

The membership of the Society at the present time is 376, of whom 284 pay annual dues. One member died early in 1914, but the notice

was not received until 1915. Nineteen new members were elected at the last annual meeting, all of whom qualified. There have been 4 deaths during the year and 1 resignation. Twenty-four members are delinquent in the payment of dues—1 for six years, 2 for four years, 3 for two years, and are therefore liable to be dropped from the roll—and 18 for one year.

One Life Member died during the year, which, with the 15 previous deaths, leaves 92 living Life Members.

With the advice of the Investment Committee, the Treasurer bought during the year one New England Telephone and Telegraph Company five per cent bond, with interest, at a cost of $1,015; and two American Agricultural Chemical Company five per cent bonds, and interest, at a cost of $2,040.28. One bond of the St. Louis, Iron Mountain and Southern Railway Company was redeemed on June 1.

RECEIPTS

Balance in treasury December 1, 1914		$1,055.28
Fellowship fees, 1912 (1)	$10.00	
1913 (1)	10.00	
1914 (8)	80.00	
1915 (261)	2,610.00	
		2,710.00
Initiation fees (19)		190.00
Interest on investments:		
Iowa Apartment House stock	50.00	
Ontario Apartment House stock	200.00	
Texas and Pacific Railroad Company bonds	100.00	
U. S. Steel Corporation bonds	150.00	
St. Louis, Iron Mountain and Southern Railway Company bond	25.00	
St. Louis and San Francisco Railroad Company equipment bond	50.00	
Fairmont and Clarksburg Traction Company bonds	100.00	
Consolidation Coal Company bonds	100.00	
Chicago Railways Company bonds	100.00	
Southern Bell Telephone and Telegraph Company bonds	100.00	
New England Telephone and Telegraph Company bond	50.00	
American Agricultural Chemical Company bonds	50.00	
Interest on deposits, Baltimore Trust Company	48.53	
		1,123.53

Case Library, accessions 1914		150.00	
Redemption of St. Louis, Iron Mountain and Southern Railroad Company bond		1,000.00	
Collection charge added to checks		.50	
Received from Secretary:			
Sales of publications	$1,078.00		
Authors' separates	88.20		
Authors' corrections	17.45		
Collection charges added to checks	.87		
Binding Bulletin	1.60		
Postage on foreign subscriptions	6.80		
		1,192.92	
			$7,422.23

EXPENDITURES

Secretary's office:			
Administration	$171.36		
Bulletin	59.30		
Allowance	1,000.00		
		$1,230.66	
Treasurer's office:			
Postage, bond, safe-deposit box	$40.00		
Allowance for clerical hire	100.00		
		140.00	
Publication of Bulletin:			
Printing	$2,437.23		
Engraving	185.44		
Editor's allowance	250.00		
		2,872.67	
Purchase of one New England Telephone and Telegraph Company five per cent bond, and interest		1,015.00	
Purchase of two American Agricultural Chemical Company five per cent bonds, and interest		2,040.28	
			7,298.61
Balance in Baltimore Trust Company December 1, 1915			123.62
			$7,422.23

Respectfully submitted,

Wm. Bullock Clark,
Treasurer.

Editor's Report

To the Council of the Geological Society of America:

The Editor submits herewith his annual report. The following tables cover statistical data for the twenty-six volumes thus far issued:

Cost.	Average—Vols. 1-20.	Vol. 21.	Vol. 22.	Vol. 23.	Vol. 24.	Vol. 25.	Vol. 26.
	pp. 610. pls. 55.	pp. 839. pls. 54.	pp. 759. pls. 31.	pp. 774. pls. 43.	pp. 755. pls. 36.	pp. 820. pls. 28.	pp. 525. pls. 27.
Letter press. Illustrations.	$1,686.58 390.99	$2,049.95 404.27	$1,660.45 260.81	$1,750.40 274.70	$1,647.90 288.80	$2,049.19 342.67	$1,076.22 171.79
Total	$2,077.57	$2,454.22	$1,921.26	$2,025.10	$1,936.70	$2,391.86	$1,248.01
Average per page.......	$3.41	$2.93	$2.53	$2.62	$2.56	$2.91	$2.37

Classification.

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1......	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2......	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3......	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4......	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5......	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6.	50	111	75	39	71	99	1	.....	63	25	4	538+x
7......	38	77	105	53	40	21	123	4	66	28	13	558+x
8......	34	50	98	5	43	67	58	14	79	8	....	446+x
9......	2	102	138	.....	44	28	64	16	64	12	....	460+x
10......	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11......	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	....	538+xi
13......	125	17	13	24	28	116	42	4	165	32	29	583+xii
14......	48	47	48	59	183	118	22	1	80	14	1	609+xi
15......	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16......	64	111	78	30	102	141	19	.....	67	22	15	636+xiii
17......	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18......	16	164	141	5	29	246	5	.....	68	40	3	717+xii
19......	106	108	29	66	30	155	32	....	56	15	20	617+x
20......	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21......	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22......	23	54	28	28	23	403	74	.....	63	49	1	747+xii
23......	75	52	126	108	19	145	134	.....	66	32	1	758+xvi
24......	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25......	34	211	54	32	156	9	175	.....	108	9	22	802+xviii
26......	.....	72	23	11	56	90	148	.....	54	44	6	504+xxi

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

The foregoing report is respectfully submitted.

THE COUNCIL.

December 28, 1915.

On motion, the report was laid on the table as usual until the following day.

ELECTION OF AUDITING COMMITTEE

The Auditing Committee, consisting of John E. Wolff, George H. Perkins, and E. B. Mathews, was then elected, and the Treasurer's report was referred to it for examination.

ELECTION OF OFFICERS

The Secretary declared the vote for officers for 1916 as follows, the ballots having been canvassed and counted by the Council in accordance with the By-Laws:

President:

JOHN M. CLARKE, Albany, New York.

First Vice-President:

J. P. IDDINGS, Brinklow, Maryland.

Second Vice-President:

HARRY FIELDING REID, Baltimore, Maryland.

Third Vice-President:

RUDOLPH RUEDEMANN, Albany, New York.

Secretary:

EDMUND OTIS HOVEY, New York City.

Treasurer:

WILLIAM BULLOCK CLARK, Baltimore, Maryland.

Editor:

JOSEPH STANLEY-BROWN, New York City.

Librarian:

FRANK R. VAN HORN, Cleveland, Ohio.

Councilors:

FRANK B. TAYLOR, Fort Wayne, Indiana.
CHARLES P. BERKEY, New York City.

ELECTION OF FELLOWS

The Secretary announced the election in due form of the following Fellows, the ballots having been canvassed and counted by the Council:

Thomas Clachar Brown, A. B., A. M., Ph. D., Bryn Mawr College, Bryn Mawr, Pennsylvania.

Charles Wilford Cook, A. B., M. S., Ph. D., University of Michigan, Ann Arbor, Michigan.

William Ebenezer Ford, Ph. B., Ph. D., Sheffield Scientific School, New Haven, Connecticut.

Charles Townsend Kirk, B. S., A. M., Ph. D., University of New Mexico, Albuquerque, New Mexico.

Donald Francis MacDonald, B. S., M. S., LL. D., United States Geological Survey, Washington, D. C.

Edgar Theodore Wherry, B. S., Ph. D., United States National Museum, Washington, D. C.

Announcement was then made by the Secretary that the Society had lost four Fellows by death during the year 1915: Theodore B. Comstock, Orville A. Derby, Joseph A. Holmes, and William J. Sutton. Since the 1914 meeting the Secretary had also received notice of the death of Arthur B. Willmott on May 8, 1914. Memorials of deceased Fellows were presented as follows:

MEMORIAL OF THEODORE BRYANT COMSTOCK

BY HEINRICH RIES

Theodore B. Comstock was born at Cuyahoga Falls, Ohio, on July 27, 1849. After graduating from school he attended the Pennsylvania State College, where he received the Bachelor of Agriculture degree in 1868. In 1870 he obtained the Bachelor of Science degree from Cornell University, and in 1886 the Doctor of Science degree from the same institution.

His first teaching position was that of Instructor in Botany in Cornell University, which he held from 1868-1870, and then left to accept a professorship of Natural Science at Pelham Priory from 1871-1872. Following this he held the following positions: Instructor in Natural Science in Cincinnati, 1873; Director of the Kirkland Summer School of Natural History in 1875, and then acting Professor of Geology in Cornell University until 1879.

Many of his former students at Cornell speak highly of the interest which he took in them and their work, and it may be of interest to note in this connection that he gave the first instruction in Economic Geology that was given at this institution. His lecture syllabus which he pub-

Theo. B. Comstock.

lished at that time contains many illustrations showing the application of geology to engineering problems.

After leaving Cornell he occupied several other teaching positions as follows: Instructor in Shaler's Harvard Summer School of Geology, 1876; Professor of Mining Engineering and Physics, University of Illinois, 1885-1889; Director Arizona School of Mines, 1891-1893; President University of Arizona, 1893-1895.

During the period that he was engaged in teaching he also was occupied with more or less field work, beginning as early as 1870, in which year he went as assistant on the Morgan Expedition to Brazil. In 1876 he served as assistant on the Kentucky Geological Survey, and in 1877 as member of an expedition to the Northwest Territories, in 1877 as assistant on the Arkansas Geological Survey, and following that in a similar capacity on the Texas Geological Survey. In the later years of his life he gave up most of his active geological work and settled in Los Angeles, California, where he died on July 26, 1915.

Doctor Comstock was a member of the following societies: Geological Society of America, of which he was an original Fellow; American Institute of Mining Engineers, Mining and Metallurgical Society, American Association for the Advancement of Science, National Geographic Society, National Educators' Association, Southern California Academy of Science, and New York Academy of Science. He was the author of many papers dealing chiefly with geological subjects, a list of which is appended.

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1876. Remarks on the hot springs and geysers and other topics illustrating the scientific value of the Yellowstone Park. Proceedings of the American Association for the Advancement of Science, volume 24, part 2, pages 97-99.

1876. Formation of geyserite pebbles in pools adjacent to the geysers of the Yellowstone Park. Abstract. Proceedings of the American Association for the Advancement of Science, volume 24, part 2, page 97.

1877. On some unexplained phenomena in the geyser basins of the Yellowstone National Park. Proceedings of the American Association for the Advancement of Science, volume 25, pages 235-239.

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1886. Supermetamorphism and volcanism. American Naturalist, volume 20, pages 1006-1008.

1886. Some peculiarities of the local drift of the Rocky Mountains. American Naturalist, volume 20, pages 925-927.

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1886. The veins of southwest Colorado. American Naturalist, volume 20, pages 1043-1044.

1886. Mining engineering at the University of Illinois. Transactions of the American Institute of Mining Engineers, volume 15, page 589.

1887. Supermetamorphism; its actuality, inducing causes, and general effects. Abstract. Proceedings of the American Association for the Advancement of Science, volume 35, pages 232-233.

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1890. A preliminary report on the geology of the central mineral region of Texas. First Annual Report of the Texas Geological Survey, pages 237-391, plate 2.

1891. Report on the geography and mineral resources of the central mineral region of Texas, chiefly south of the San Saba River, north of the Pedernales River, west of Burnet, and east of Menardsville and Junction City. Second Annual Report of the Texas Geological Survey, pages 553-664, 3 maps.

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1891. A preliminary report on parts of counties of Menard, Concho, Tom Green, Sutton, Schleicher, Crockett, Valverde, Kinney, Maverick, Uvalde, Edwards, Bandera, Kerr, and Gillespie, Texas. Second Report of Progress of the Texas Geological Survey, pages 43-54.

1892. Valuable experiments in vein formation. Science, volume 19, page 214.

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Yours truly,
Orville A. Derby

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1901. The geology and vein phenomena of Arizona. Transactions of the American Institute of Mining Engineers, volume 30, pages 1038-1101, 1 figure.

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1905. Superficial blackening and discoloration of rocks, especially in desert regions. Transactions of the American Institute of Mining Engineers, volume 35, pages 1014-1017.

1902. Geological notes. Bulletin of the Southern California Academy of Sciences, volume 1, page 74.

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MEMORIAL OF ORVILLE A. DERBY

BY JOHN C. BRANNER

Orville Adelbert Derby was born at Kelloggsville, New York, July 23, 1851; and died by his own hand at Rio de Janeiro, Brazil, November 27, 1915. He was the third son of John C. Derby and Malvina A. Lindsay Derby, and was reared on a farm near Kelloggsville, in Cayuga County, in the "Finger Lakes" region of New York State, about 16 miles southeast of Auburn.

Derby entered Cornell University in 1869, and while yet a freshman he became so interested in geology and was such a promising student that he was selected by Prof. Charles Fred Hartt, then professor of geology at Cornell, to accompany him on a trip to Brazil in the summer of 1870. An incident showing a characteristic trait of the man had something to do with his selection for assistant on that trip and for his subsequent promotions. Professor Hartt had to leave the university for an absence of two weeks. He was a bit uncertain as to what could be done during his absence with this very new student of his. At a venture he gave him Hall's volume on the fossil bryozoa of New York—a work that would certainly have cooled the unguided ardor of most beginners. When Hartt came back at the end of two weeks Derby was patiently pegging away on the bryozoa. Hartt's heart warmed to a student who had the grit to stick to his uninspiring work, and shortly thereafter the opportunity to visit Brazil was given him. Derby gladly accepted the invitation, and in doing so he determined both his career and the whole course of his life.

On his first voyage to South America he went to Pernambuco and made the first considerable collections of fossils ever made at Maria Farinha.

In the summer of 1871 he went to Brazil with Hartt again, this time visiting the Amazon Valley and making an important collection of Carboniferous fossils from the limestones at Itaituba, on the lower Tapajos River.

In the interval between 1871 and 1873 he was occupied with his studies, and in 1873 he graduated at Cornell University; the year following he continued his geological work for the master's degree, which he received in June, 1874. His thesis was "On the Carboniferous brachiopoda of Itaituba, Rio Tapajos," and was published as number 2 of Volume I of the Bulletin of Cornell University, Ithaca, 1874. That was Derby's first publication on the geology of Brazil, and it is not only a valuable paper in itself, but it is especially interesting in view of subsequent developments. The Itaituba fossils were in compact limestone, but as they were silicified, they could be obtained in satisfactory form only by dissolving away the surrounding rock—a long and tedious process which would have thoroughly discouraged most young men of Derby's age.

In 1873 Derby was appointed instructor in geology in Cornell, and in the summer of 1874 Professor Hartt made arrangements to go to Brazil again. Leave of absence was obtained, Derby was placed in charge of the work of instruction in the department, and in September, 1874, Hartt went to Brazil again, taking Branner with him as his only assistant.

Arriving in Rio de Janeiro, Hartt at once devoted all his energies to interesting the leading men in a geological survey of the empire, and by the end of a year the survey was provided for, and O. A. Derby, Richard Rathbun, and E. F. Pacheco Jordão were named as assistants of the new "Commissão Geologica do Imperio do Brasil." In December, 1875, Derby reached Rio de Janeiro and began his work under the government. He held this position less than two years, for, through a change of ministry, the survey was abolished in 1877, and Hartt died in Rio that same year. Shortly after the extinction of the survey, however, Derby was given a position in the National Museum at Rio as curator in charge of geology. He remained in the museum until 1886, when he was made State Geologist of the Brazilian State of São Paulo.

The establishment of the São Paulo Survey was a step of great importance to geological science in Brazil, for Derby's knowledge of and interest in the geology of the country as a whole enabled him to grasp more firmly the geological problems of that particular State, and at the same time he became and remained the leading authority on the geology of Brazil. He was State Geologist of São Paulo until 1904, when he resigned.

In January, 1907, a new federal geological survey was provided for under Dr. Miguel Calmon, who was then minister of public works, and

Derby was made its chief—a position he held during the rest of his life. The appropriations were necessarily small at the outset, but the work undertaken was of great importance to Brazil, for sooner or later it was to point the way to an intelligent and scientific development of the natural resources of the country.

The first edition of Branner's *Geologia Elementar* was thus dedicated:

"To Orville A. Derby, who has devoted his life to the study of the geology of Brazil, and has done more than any one else to solve its many problems, this work is affectionately dedicated."

This is a brief and mild statement of Derby's great service to Brazil and to the science of geology, without mentioning his many other services to science and to that country.

Visitors to Brazil who were interested in geology always found him helpful in connection with their work. Dr. J. B. Woodworth, of Harvard, who went to Brazil in 1908 to study the Permian glaciation of the Southern States of that country, says that "without his aid and personal attendance it would not have been possible for me to have carried on the Shaler Memorial Expedition in Brazil to a successful issue in anything like the time in which that work was accomplished. With true Latin-American courtesy he paved the way for me to find what he would have been proud himself to have discovered—the actual occurrence of glaciated pebbles in the tillite beds of Paraná."

First and last, Derby was a paleontologist. He had no fondness for administrative work; he was but little interested in structural geology or in its methods; he was forced by circumstances into some acquaintance with microscopic petrography; but his interest in paleontology was genuine, deep, and all-comprehensive. From all the cares of office and the worriments of life he found relief and happiness in boxes of fragments of fossils that most paleontologists would have put away as not worth while.

It was chiefly to this interest of his in paleontology that we owe Dr. C. A. White's "Contributions to the Paleontology of Brazil," published at Rio in 1887, and the following valuable works by Dr. John M. Clark: "Trilobites of the Ereré and Maecurú sandstones," Rio, 1896; "Upper Silurian fauna of Rio Trombetas," Rio, 1899; "Devonian mollusks of the State of Pará," Rio, 1899, and "Devonian fossils of Paraná," Rio, 1913. Besides these more important publications there are many smaller papers on paleontology that can not be mentioned here, and there still remains unpublished an important volume by D. S. Jordan on the Cretaceous fossil fishes of Ceará.

During the last eight years Derby has given much of his time to the study of *Psaronius* and its relationships. The last of his published papers was on the stem structure of *Tietea singularis*, which appeared in the American Journal of Science for March, 1915, pages 251-260.

Having to undertake work in regions but poorly supplied with maps, one of his first and most important duties, when he became State Geologist of São Paulo, was the inauguration of topographic work. This work was intrusted to Horace E. Williams, an able and energetic young American, to whom the State of São Paulo and the scientific world are indebted for an excellent series of topographic maps, on a scale of 1 to 100,000, to say nothing of his explorations of the western portions of that State, his work on the Serra da Canastra, etcetera.

Derby's own list of publications on the geology of Brazil numbers 125 papers. Naturally they embrace a wide range of subjects. Ten of his papers relate to the geology and genesis of the Brazilian diamonds. He became interested in the early cartography of Brazil and published a number of papers on the subject.

As an author and as a scientific reasoner, he was an extremely cautious man, so much so that the word "hedge" was constantly on his lips, both for his own guidance and as a warning to his assistants.

The last evening I spent in his rooms at Rio de Janeiro he referred to this personal trait and remarked that it had prevented his marrying; that he was too cautious to take the risk. This cautiousness of his was probably the real reason for some of the long delays in publishing his results, which led to the tying up of his own results and those of his assistants. Without doubt he hoped the delays would enable him to put everything beyond question and to make his reports final and complete instead of preliminary and tentative. But the delays were prolonged from year to year, until his assistants became discouraged and the government more or less exasperated at the lack of practical results for such great and long continued expenditures. It was largely this long delay that finally led to his resignation as State Geologist of São Paulo.

Derby never felt obliged to show results. After he had been State Geologist of São Paulo for ten or twelve years and had published next to nothing on the geology of that State, I asked him point blank and with some feeling where his results were. He replied: "They are in my head." We had to change the subject. But the important fact behind his delays is that the geology of São Paulo is difficult and involves problems that he had not been able to settle to his own satisfaction, and he was unwilling to commit himself to paper and thus lay himself open to adverse criticism.

It seemed unfortunate for Brazil, for himself, and for the cause of

science that he was unable to bring himself to take an active interest in the economic geology of the country; but his first and only interest in geology was in geology as a pure science. To him a fossil was a thing of beauty, of interest, and value, and a joy forever; but a mine or an industry was, after all, only an industry whose main object was money-getting.

It goes without saying that Derby and I did not always agree about geological questions, but our very disagreements tended to stimulate careful work and finally to disclose the truth. An interesting illustration was our disagreement in regard to certain beds in the black diamond regions of Bahia; he called them Paraguassú and I called them Caboclo. After a year of proving each other in the wrong, he was induced to send his assistant, Roderic Crandall, to the region in question to settle the dispute. Crandall went and reported that we were not speaking of the same things; that both series were legitimate, and that we were both right.

Derby was a man of unlimited gift. When once he decided on a course of action, nothing turned him to the right or to the left. His whole life is a demonstration of his power to make good in spite of obstacles that would have been insurmountable for most men—his determination to devote his life to the geology of Brazil, cost what it might.

How many of us would have lived for forty years in a foreign country, cut off, as he was, from all personal contact with the geologists of the world at large and from the people of his own race and from his own family? From the time he went to Rio, in 1875, to the day of his death—a space of forty years—he visited the United States only twice. The first of these visits was from January to June of 1883, when he went to Washington to arrange for the publication of Dr. C. A. White's Contributions to the Paleontology of Brazil, an epoch-making work on South American paleontology. He spent part of that time in Boston, New Haven, New York, and Philadelphia. His other visit was made in 1890, when he attended the Indianapolis meeting of the American Association, and returned to Rio by way of England.

When the Commissão Geologica was stopped, in 1877, the rest of us took to our heels. Not so Derby; he was not to be stampeded by a simple lack of funds or of employment; he meant to save the results of the work of Hartt and of his colleagues, and, so far as it could be done, he did it.

Personally Derby was one of the kindest hearted and most affectionate men I have ever known. His time, his sympathies, and his last dollar were at the service of his friends; and his right hand knew nothing of the kind deeds done by his left. The beggars in the streets found him their easiest victim.

He was held in the highest esteem in the community in which he lived. He stood for uprightness and honorable dealing, and he was never the willing tool of designing adventurers. For many years he has been justly regarded as the leading geologist in South America, and his standing is due not to the fact that there are but few geologists in South America, but to his ability and to his excellent work.

In 1892 he was awarded the Wollaston prize of the Geological Society of London, while his distinguished services led to his being made one of the associate editors of the Journal of Geology and to his election to membership in various learned societies in different parts of the world. He was a frequent contributor to the American Journal of Science. He was naturalized as a Brazilian citizen a few months before his death.*

The circumstances that led to Derby's suicide are not clearly known, or rather they are not clearly understood. Neither the published accounts of all the details available to the authorities nor the many private letters received from mutual friends throw much light on the case. The act was committed in his rooms in the Stranger's Hotel in Rio, where he had lived for eight years. The evening preceding his death was spent at the home of a Brazilian friend and he went to his own rooms about midnight. The next morning he was called as usual, took his bath, drank his coffee, and read the morning papers. About 10 o'clock a messenger going to his room found him lying across his bed with a bullet-hole through his head and the revolver still grasped in his dead hand. He left no word of explanation or complaint about anything or against any one.

The general impression seems to be that his suicide was due to disappointment on account of the reduction by the government of the appropriations for his work. A few feeble efforts have been made to find other explanations for his act, but this must be and is accepted as the only genuine one.

The history of his struggles to keep the scientific work intrusted to him out of politics and to make it efficient is nothing new. Scientific men the world over have often been in similar positions. In the present case there is no doubt but that the matter was complicated by the financial situation in Brazil brought about by the war in Europe. The government was hard pressed financially and it was absolutely necessary to reduce expenses to the lowest possible point. It was not unnatural under

* His successor as director of the Brazilian Survey is Dr. L. F. Gonzaga de Campos, who has been one of the geologists of the survey since it was begun. Doctor Campos is the author of a number of valuable papers on Brazilian Geology and a thoroughly conscientious man of wide personal acquaintance with the geology of Brazil.

the circumstances that the geological service should have been selected as the one that could be reduced without producing serious confusion in the administration of the government.

The Brazilian newspapers all speak of him in the highest possible terms, and his death is generally and properly looked on in Brazil as a great national loss.

His suicide itself was his last and his most emphatic protest against the extinction of geologic work—the final culminating expression of his profound interest in and devotion to the welfare of the country he had served faithfully for forty years.

A list of his papers on the geology of Brazil up to 1909 is given in this Bulletin, volume 20, papers 36 to 42. To that list should be added the following titles, that have appeared since the publication of that list:

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Illustrations of the stem structure of *Tietea singularis*. American Journal of Science, volume XXXIX, March, 1915, pages 251-260.

MEMORIAL OF JOSEPH AUSTIN HOLMES [1]

BY JOSEPH HYDE PRATT

The life of Dr. Joseph Austin Holmes was devoted to the development and welfare of his country, and in his death the people of the United States have lost one of their most efficient and valuable public servants. He was a man who put duty first, and in carrying out this ideal he gave his life in an endeavor to improve the condition and safety of the miners. He did not know the word "failure;" and, where other men would have failed, he has been able to accomplish the results desired. It is granted to but few men to be able in the few years of their life's activity to do that which will leave a permanent influence and impress on an industry; but to Doctor Holmes, whose life we are now commemorating, this distinction was allotted.

Due almost entirely to his energy and efforts, there has been created throughout this country an organized movement looking to the preservation of human life; and, although his first work was directed toward the prevention of mine accidents and safety and welfare of the hundreds of thousands of men who daily risk their lives in the production of fuel, so necessary to the nation's industry and commerce, it developed the "safety first" idea that has spread to nearly every industry and into all walks of life. These words are almost synonymous with the word "Holmes," and wherever we see "safety first" we are reminded of the wonderful achievements of this man. He has not only left his impress on an industry, but has also created an organization which will live as long as our government exists, and is a monument to the tireless energy, public-spiritedness, and unselfishness of the man who is responsible for its creation. I refer to the Bureau of Mines, whose foundation he laid by many feats of exacting labor and fruitful work, and who, by masterful generalship and arguments, as he only could use, carried the bill to establish the Bureau of Mines successfully through an unsympathetic Congress.

To Dr. Charles D. Walcott, former Director of the United States Geological Survey and now Secretary of the Smithsonian Institution, must be given the credit of recognizing those qualities of character and ability in Mr. Holmes which he realized were necessary in a man who could not only lay the foundation and build up an organization that would lead to a Bureau of Mines, but who would also be able to direct it after its creation. In a recent communication from Doctor Walcott, he wrote:

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[1] Read at the annual meeting of the Geological Society of America, Washington, D. C., December 28, 1915.

J. A. Holmes

"About 1900 it became more and more evident that he (Doctor Holmes) was a man of broad conceptions and fitted to undertake work of national scope, and it was with great pleasure that I learned, in 1904, that he was willing to give all of his time and energy to the development of the Section of Mines and Mining in the Federal Survey. I told him that as soon as the work was sufficiently well organized it would be made a Division of the Survey and undoubtedly lead to the creation of a Bureau of Mines and Mining. He entered into the work with a zeal and intelligence that was not fully understood by his immediate associates; but the work steadily grew and, in 1910, he was appointed Director of the Bureau of Mines."

His appointment, however, was not attained without very severe opposition from a Secretary who was hostile to Doctor Holmes, and it is rumored that this important position was offered to several other men; but, to the credit of the men of science of this country, it can be said that they all refused to accept what all knew rightfully belonged to another. Those who knew Doctor Holmes, having confidence in his ability and believing that he was the logical head for the new Bureau, were persistent in their demand that he should receive the appointment. It is not generally known how near the Bureau came to losing Doctor Holmes as its Director and how near the University of West Virginia came to securing him as its president; and, as an incident bearing on this is illustrative of the loyalty of Doctor Holmes' friends, I wish to quote in part a few lines from a letter I recently received from Dr. I. C. White, State Geologist of West Virginia:

"It was during this discouraging period of his life, just before the appointment of a Director of the Bureau of Mines, when he had given up all hope of receiving the appointment, that he came up from Pittsburgh to spend the week end at the writer's home in Morgantown, West Virginia. He was weary and care-worn from the long and disappointing vigil, but gentle and loving as ever. No word of reproach or bitterness escaped his lips. If he could not serve his country in an edifice his own hands had so largely constructed, he was ready to give his services to a State that had stood by him in his long battle, and where he knew he would be among appreciative friends. The State University of West Virginia was seeking a president, and one of the purposes of Doctor Holmes' visit to my home was to acquaint the writer, who had ever been his trusted friend, with the fact that he had despaired of being appointed Director of the United States Bureau of Mines, and would accept the presidency of the University of West Virginia if the regents of the same would make the tender."

Fortunately for the industry, Doctor White and others, realizing that for the success of the Bureau of Mines it was necessary that Doctor Holmes should be its head, decided, out of genuine loyalty to him and appreciation of his work, that they would not place his name for action before the regents of the University until President Taft had actually

bestowed the directorship of the Bureau of Mines on some one else. His friends' belief in what President Taft would finally do was confirmed a few days' later, when the appointment of Doctor Holmes was announced from the White House.

That he was a wise selection is evidenced by the wonderful development of the Bureau under his administration. The work he had planned as Chief of the Technologic Branch of the United States Geological Survey developed rapidly, aided by Congress, which widened the scope and enlarged the purposes of the Bureau. The principal investigations taken up under Doctor Holmes' directorship and the results accomplished are as follows:

An investigation in regard to the improper use of explosives and the use of improper explosives.

Investigation in regard to better lights for mines. Result, the establishment of a permissible list of portable electric lamps for use in dangerous mines.

In developing rescue work Doctor Holmes introduced into this country the so-called "oxygen breathing apparatus." Result, such apparatus is now not only widely used in mine-rescue work, but is being adopted by manufacturing plants and by city fire departments. There are today six mine-rescue stations, eight mine-rescue cars, and one rescue motor truck operated by the Bureau of Mines. There are 76 mine-rescue stations that have been established by mining companies, at which there are 1,200 sets of artificial breathing apparatus in addition to the auxiliary equipment for first-aid and fire-fighting work. There are also twelve mine-rescue cars being operated by mining companies.

Investigations into the cause of disasters and the recommendations made by the Bureau have resulted in an ever decreasing death rate.

The investigation of coal dust and explosions therefrom was one of the most important lines of investigation that Doctor Holmes took up. The result today is that the entire mining industry, including operators and miners, is convinced that coal dust will explode, and recognize the danger from it; and mine operators and State officials are following the recommendations of the Bureau to prevent dust explosions.

Investigations have been conducted regarding smelter smoke wastes and wastes in the treatment of rare minerals and metals. Doctor Holmes emphasized the need of such investigations, indicating that there was at least $1,000,000 a day being wasted or lost in the present methods of mining and utilization of our mineral resources.

Investigations regarding the extraction of radium from its ores have resulted in the development of a process through which it will be possible

to greatly reduce the cost of radium compounds to the consumer. "The process is to be patented and dedicated to the public." [2]

Investigations have been started to reduce the great loss of $75,000,000 annually, due to coking coal in beehive ovens. As a result already some of this loss has been reduced through the use of by-product ovens and the utilization of the by-products obtained.

Doctor Holmes called attention to the annual waste of over $4,500,000 in brass-furnace practice, and then had prepared a report showing how, by practical means, this waste can be largely prevented.

These are some of the investigations that Doctor Holmes has had taken up by the Bureau of Mines, and they illustrate the wide scope of the work he was planning for the Bureau to undertake. Its development into one of the most important of all the Federal Bureaus has been phenomenal and is due not only to the indefatigable work of the Director, but to the fact that he was a splendid judge of men and their capacity for work and was able to surround himself with the type of men who were able to carry out the plans his master mind had conceived, and these men were loyal and true to him.

He was thoughtful and considerate of his associates; and while he may have demanded much of them, he always gave them full credit for work done; and of the reports of the investigations carried out by the Bureau but very few bear his name as author. Credit is given to him who carried on the investigation. Doctor Holmes planned the character of the investigation, then put it up to one of his associates to do the detailed work. What he wanted was results. He had little time to write for publication or to think about personal advancement, and he left it to his associates to do the writing and give him the results—and results he surely obtained.

Although Doctor Holmes is the author of but comparatively few publications, yet he has been personally responsible for the publication of many important scientific and economic papers, because he has had the foresight to open up new fields of investigation and secure the properly trained men to carry on the work he outlined. I doubt if there has ever been a man who surpassed him in this respect.

This faculty of Doctor Holmes showed itself soon after he became State Geologist of North Carolina in 1891. In this position he had wide latitude for planning out a varied line of investigations relating to many subjects, inasmuch as the object of the State Survey was the investigation of all natural resources of the State. Almost as soon as he was appointed State Geologist, he began to plan new lines of work and to call in to assist

[2] Van H. Manning: Jour. Ind. and Eng. Chem., vol. 7, No. 8, p. 716, Aug., 1915.

him men who were fully qualified to carry on the investigation he desired. Thus you find associated with him during the first years of his directorship of the State Survey such men as Prof. George Williams, of Johns Hopkins; Prof. S. L. Penfield, of Yale; Dr. George F. Kunz, of New York; Prof. F. P. Venable, of the University of North Carolina; Dr. George P. Merrill, of the National Museum at Washington; Prof. George Swain, of the Massachusetts School of Technology; Prof. Thomas L. Watson, of the University of Virginia; Prof. H. V. Wilson, of the University of North Carolina; Prof. William Cain, of the University of North Carolina; Mr. H. B. C. Nitze, Mr. Gifford Pinchot, of Washington; Prof. Heinrich Ries, of Cornell, and others. The published reports of the State Survey, similarly as those of the Bureau of Mines, seldom bear the name of Holmes as one of the authors.

Doctor Holmes did a great deal to broaden the scope of the State Geological surveys and to demonstrate that there could be and should be a close cooperation between the State and Federal surveys. There was always most friendly cooperation between the North Carolina Survey and the Federal Survey; and, although the State received very largely from the Federal Survey, it gave very largely in return, for Doctor Holmes was always ready to give his time and energy to any work which promised to be of service to the Federal Survey; and he was often called in consultation regarding the work of that Survey. Doctor Walcott, who was then Director, states that he was early impressed with Mr. Holmes' thoroughness and the quality of his work as State Geologist. In the Geological Survey his most important work was probably the application of geology to the industrial development of the country. He started this in the State Survey, but later introduced it into the Federal Survey.

As State Geologist he became very much interested in the preservation of the forests of the southern Appalachian region, and it is due largely to his work as State Geologist that the Weeks bill was passed by Congress, which has resulted in the purchase of forest areas to be used for forest reservations in the southern Appalachian region and the White Mountain region. It was under the supervision of Doctor Holmes that the mass of evidence was collected, which proved to the congressional committees that it was absolutely necessary for Congress to take some action to prevent the destruction of the forests of these two areas in order to protect the flow of navigable streams.

In connection with an investigation relating to our turpentine industry, he had experimental work carried on in regard to the cup and gutter method, which is now in general use in this industry. He also had investigations made as to the practicability of the reproduction of the long-

leaf pine, and an actual demonstration in planting of seed proved the feasibility of such reproduction.

Doctor Holmes also started the "good roads" movement in North Carolina, and one of the first publications of the State Survey was a report on "Road materials and road construction in North Carolina." While his work in connection with the roads was almost entirely from the educational standpoint, yet it was this work that made it possible for his successor to obtain, through the North Carolina General Assembly, the creation of, first, a Highway Division of the Survey, and later of a State Highway Commission.

In the State work Doctor Holmes also began investigations in relation to the water powers, mineral waters, underground water supplies, timber resources, mineral resources, and fisheries of the State; but a limited treasury and lack of time prevented him from carrying these out as rapidly as he desired, and it was left to his successor to complete some of them.

During his term of office as State Geologist, 1891 to 1905, the Survey published twenty bulletins and economic papers, giving the results of investigations that he had started. In 1905 the act creating the Survey was repealed and a new act, which was prepared by Doctor Holmes, was passed by the General Assembly of 1905. This created the North Carolina Geological and Economic Survey.

Doctor Holmes brought geology to this people and made them realize its value and application in the arts.

In connection with the investigation of the fisheries of the State, Doctor Holmes was the leading spirit in the establishment of the Biological Laboratory at Beaufort. In June, 1897, after consultation with Doctor Holmes and Prof. H. V. Wilson, of the University of North Carolina, the United States Commissioner of Fisheries established at Beaufort, North Carolina, a temporary station for the investigation of the marine fauna and flora of the Southern coast. Professor Wilson was appointed director, and for the next three years he and Doctor Holmes devoted much time and thought to its development. Congress finally made an appropriation for the establishment of a permanent laboratory, but made no appropriation for the purchase of a site. Doctor Holmes recommended a site and arranged for its private purchase and its donation to the government. He, with Professor Wilson, drew up the outline plans for the laboratory buildings, and he remained in close touch with the work of the laboratory until his resignation as State Geologist. This work of Doctor Holmes had an important bearing on the fisheries of the State of North Carolina, as it started the interest of the people of the State in the value of the

fisheries, and finally resulted, some years after the resignation of Doctor Holmes as State Geologist, in the creation of the Fisheries Commission of the State of North Carolina.

Doctor Holmes' work as State Geologist had brought him prominently before the public, and in 1903 he was chosen Director of the Department of Mines and Metallurgy at the Saint Louis World's Fair. He accepted this appointment and had charge of and organized that department. He planned the exhibits and introduced new features for the exhibits, which have since been adopted by all succeeding expositions. These new features made the Mine Building of the Saint Louis Exposition the most successful and instructive mining exhibit that was ever made at any exposition. For special services rendered at this exposition he was decorated by several foreign governments. In connection with the mining exhibit, he suggested that an investigation be made of the fuels of the United States, and was successful in persuading Congress to authorize the investigation and make the necessary appropriation with which to carry on the work. Doctor Holmes and, at his suggestion, two representatives of the United States Geological Survey were created a committee to carry on the investigations which were made during the years 1904 and 1905. Although Director of the Department of Mines at Saint Louis, Doctor Holmes continued to have general supervision of the work of the North Carolina Geological Survey. Early in 1905 the Director of the United States Geological Survey appointed Doctor Holmes to take individual charge of the fuel investigations, and soon after he was appointed Chief of the Division of Technology of the Federal Survey, and then severed his connection with the State Geological Survey.

While connected with the Federal Survey, Doctor Holmes examined mine experiment stations and mine-rescue stations in Great Britain, Belgium, France, and Germany, and it was the result of these studies that led to the inauguration of the movement for mine-rescue work in this country.

In 1907 President Roosevelt, on Doctor Holmes' recommendation, secured the appointment by the governments of Great Britain, Germany, and Belgium of one expert engineer from each of these countries to visit the United States and then visit, with Doctor Holmes, the more important coal fields of this country. This was done in order to determine to what extent the safety practices used in other mining countries might be introduced into the United States. It was on the basis of the findings of these engineers that Doctor Holmes developed and organized his investigations relating to mine explosions, etcetera.

In 1908, when President Roosevelt took up the question of the conservation of our natural resources, Doctor Holmes was appointed a member of the National Conservation Commission, and he had charge of the inventory of the nation's mineral resources.

In all Doctor Holmes' work his central thought has always been the development of the mining industry and the improvement of conditions affecting the miner. In carrying out these great ideas, he thought only of the object to be attained and paid little or no heed to personal attacks or opposition, such as inevitably accompanies a forward movement or investigation that requires the cooperation of both the legislative and administrative departments of our government. When, however, an attack was made on him that appeared to endanger the work itself in which he was engaged, he was then ready to put forth all his efforts to meet and defeat the opposition.

Doctor Holmes was human as the rest of us and occasionally was forgetful in regard to certain things that were to be done. This characteristic of his sometimes led to severe criticism of his work by those who were not thoroughly acquainted with him. Whenever any apparent neglect on his part was called to his attention, the matter was instantly taken care of and ample apology made for the oversight. Doctor Holmes was excessively careful to observe all the little courtesies of life and was a splendid representative of the Southern Christian gentleman.

Doctor Holmes was born at Laurens, South Carolina, November 23, 1859, and died at Denver, Colorado, July, 1915, after nearly a year's illness and fight against tuberculosis. His ill health was undoubtedly brought on by severe exposure in connection with the examination of mines after explosions and of hardships endured in investigations regarding mining conditions in Alaska. His parents were Z. L. and Catherine (Nickles) Holmes.

His early education was in the schools of South Carolina, but his university work was at Cornell, where he graduated in 1881, taking the degree of B. S. Later he received the degree of D. Sc. from the University of Pittsburgh, and in 1909 the degree of LL. D. from the University of North Carolina. During his college course Doctor Holmes devoted especial attention to chemistry (including the chemistry of explosives), to metallurgy, geology, general physics, and mining. He visited mining regions and metallurgical plants in many parts of the United States, Germany, France, Great Britain, and Belgium.

In the fall of 1881 he became professor of Geology and Natural History in the University of North Carolina, and held this position until 1891, when he became State Geologist.

On October 20, 1887, Doctor Holmes married Miss Jeannie I. Sprunt, of Wilmington, North Carolina.

Doctor Holmes was a fellow and charter member of the Geological Society of America; fellow of the American Association for the Advancement of Science; member of the American Institute of Mining Engineers, American Society for Testing Materials, and American Society of Mechanical Engineers. He was appointed a member of the Mining Legislation Committee of Illinois; one of the founders of the Elisha Mitchell Scientific Society; member of the Sigma Xi Scientific Society; member of the Washington Academy of Science, Saint Louis Academy of Science, and the North Carolina Academy of Science; member of the Cosmos Club of Washington and the Engineers' Club of New York.

In closing this sketch let me further express my feelings and thought regarding Doctor Holmes in the words of several friends who were very close to him:

"Doctor Holmes stands as one of the finest examples of unselfish devotion to the cause which he championed, even to the extent of giving his life for it. Mining in America in its national aspect is more deeply indebted to him on its scientific, operating, and industrial sides than to any one other individual. It seems most unfortunate that Doctor Holmes did not live to aid the movement to improve the laws affecting mines and mining; but, with the Bureau of Mines firmly established, and cooperating with the thoughtful mining engineers and operators throughout the country, the results he hoped to see should be speedily obtained.

"Charles D. Walcott."

"Ever thoughtful, resourceful, a great organizer, a clear, logical, and eloquent speaker, a splendid judge of men and their capacity to do the work his master mind had planned, the United States Bureau of Mines, founded only in 1910, has under his leadership rapidly grown to be one of the most important of all government agencies. . . .

"His monument is the United States Bureau of Mines, and his memory will be cherished forever in the hearts of countless miners, whose lives he has rendered safer in the perilous occupation they follow, and without the product of whose busy hands our present civilization could not exist. Although cut down in but little beyond the prime of life, he has left us an example of what glorious achievements, indomitable will, and untiring work can accomplish. The great Bureau he so largely created and so successfully directed will continue its brilliant work along the path he so skilfully blazed, since, thanks to a very able and conscientious Secretary of the Interior, his successor is in thorough accord with the high ideals of the former chief, and was ever his efficient helper.

"I. C. White."

"In the death of Doctor Holmes the people of the United States lose one of their most remarkable and efficient public servants. And the saddest part of it all is that Doctor Holmes is a victim of overwork—a too great devotion to

the duties which had been assigned to him in behalf of the safety of the million miners in the United States. He was one of the most enthusiastic, indefatigable workers I ever had the pleasure of associating with. His mind was continually on the yearly death toll of the miners, and, although taken away in the prime of his life, he has already accomplished much in reducing the terrible death rate. In the last five years of his life he saw a slowly but steadily decreasing death rate, and while it gave him much joy, it only added to his almost superhuman efforts in behalf of the men.

"VAN. H. MANNING."

A full list of Doctor Holmes' reports and more important scientific papers is given in his bibliography, which appears at the close of this sketch. The picture of Doctor Holmes that accompanies this sketch was selected by Mrs. Holmes.

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MEMORIAL OF WILLIAM JOHN SUTTON

BY WILLIAM FLEET ROBERTSON [1]

William John Sutton was born in Kincardine, Ontario, on January 19, 1859.

His earlier education was acquired in the public schools of Walkerton, Ontario, and later at Trinity College School, Port Hope, Ontario. This was followed by special courses in geology and assaying at Cornell and the Columbia School of Mines.

In 1887 Mr. Sutton moved to British Columbia on the first flood of the "to the West" movement created by the completion of the Canadian Pacific Railway. Settling in Victoria, he was very shortly after appointed the official government assayer, which position he held for some two years.

The report of the Minister of Mines of British Columbia for the year 1888 contains Mr. Sutton's first published report, "A description of the mineral resources of the province" and "List of economic minerals found in the province."

In those earlier days in British Columbia, although placer gold mining had been extensively developed in the interior and coal mining was in operation on the seaboard of Vancouver Island, lode mining had hardly gained even a foothold and the work was in the hands of "practical" men, who, it is more than suspected, classed geologists, chemists, and poets together as purely "ornamental frills," to be respected individually, but of little economic value.

Finding scant financial encouragement in his chosen work, Mr. Sutton, like most of the earlier pioneers, not having "come West for his health," felt obliged to resign from his position as government assayer and entered the lumber business, subsequently securing large tracts of timber and land.

Having thus acquired some little competency, his love for his earlier studies in geology and mineralogy again asserted itself, and feeling the

[1] Written by Mr. Robertson at the request of Dr. R. W. Brock.

need for further instruction in these pursuits, which at that time could not be had here in the West, he went, in 1894, to the Michigan School of Mines at Houghton, Michigan, where he remained four years, taking a technical course and continuing as instructor in mineralogy and crystallography.

Returning to British Columbia, Mr. Sutton entered the service of the Wellington Colliery Company as geologist, and on the company's interests being acquired by the Canadian Collieries (Dunsmuir), Limited, he continued with the new company in the same capacity until the time of his death, on May 19, 1914.

During his connection with the Wellington Colliery Company, Mr. Sutton also acted as consulting geologist for Mr. James Dunsmuir, who had numerous interests in the various metalliferous mining camps of the province.

The Wellington Colliery Company owned the coal rights under a large portion of Vancouver Island, and these were unsurveyed and undefined; it therefore fell to Mr. Sutton to survey and geologically map all these areas and to prospect portions of these for workable coal. In this way he mapped geologically the greater part of the island, an extensive and valuable piece of work, but of such a confidential nature that its publication would have been contrary to the interests of the company.

In connection with this work and his personal timber interests, he acquired a knowledge of the geology of Vancouver Island probably more extensive than that possessed by any other person. He was regarded as *the* authority on the Cretaceous coal-bearing strata of Vancouver Island, and his opinions were often sought by the government departments.

It was always a matter of sincere regret on Mr. Sutton's part and that of his friends that his official position prevented the publication of the mass of valuable geological information he had acquired. It seemed as though he had been obliged by his commercial duties to "keep his light under a bushel," and few but his personal friends and professional *confrères* realized the extent of his geological work.

So irksome to Mr. Sutton had become this feeling of restraint that he had planned to retire from commercial life and to devote his time to the preparation of his geological and mineralogical data for publication and had practically arranged with the writer that such should be done, under the auspices of the British Columbia Bureau of Mines. This intention was, however, frustrated by his sudden death, at Ucluelet, on the west coast of Vancouver Island, while in the active pursuit of his work.

Mr. Sutton was a man of unusually strong physique and his death was probably due to heart failure, as he was never sparing of himself in his

A. B. Willmott

work, and there were few professional woodsmen who could keep pace with him through the dense forests.

While geology was his work, mineralogy was his hobby, and he had personally collected one of the best collections extant of British Columbia rocks and minerals, which he had amplified with rarer and more unique specimens acquired during a trip to Europe.

His interests in science were varied. He was an energetic member of the Natural History Society of British Columbia, being president of the Society in 1912 and 1913, before which he read a number of papers, chiefly on forestry and its conservation.

He was also a member of the Royal Astronomical Society of Canada, the Canadian Mining Institute, and the American Institute of Mining Engineers.

Mr. Sutton's death is a great loss to scientific investigation in British Columbia, where devotees to science are few, and it seems a great pity that he was unable to leave more published records of his store of information.

MEMORIAL OF A. B. WILLMOTT

BY A. P. COLEMAN

Arthur Brown Willmott, son of Rev. J. C. Willmott, of Milton, Ontario, passed away, after a long illness, on May 8, 1914, in his forty-eighth year. He graduated from Victoria University, Cobourg, Ontario, in 1887, taking his arts and science degrees at the same time. He attended Harvard University in 1891, and became professor of chemistry and mineralogy in McMaster University, Toronto, in 1892, continuing in that position until 1900, when he turned his attention to economic geology, becoming field geologist and later manager of mines for the Lake Superior corporation at Sault Ste. Marie, Ontario.

In 1893 he married Mina B. Sanders, daughter of W. B. Sanders, of Stouffville, Ontario.

Mr. Willmott was for some years in the employ of the Bureau of Mines of Ontario, working in Precambrian areas. His greatest interest was in the iron deposits of the Keewatin of Ontario, especially in the Michipicoten region, and he became a recognized authority on the difficult geological and economic problems of the region.

In 1910 Mr. Willmott returned to Toronto to take up work as a consulting mining engineer and to assume the *active* management of several mining companies. In 1913 he was again connected with the Lake Superior corporation in a consulting capacity, which position he held till his death.

The late Mr. Willmott was a most genial and lovable man, who made friends among all classes, and his premature death has been a sorrow to his many friends, as well as a serious loss to science. He leaves a widow and a son and daughter.

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The Society then proceeded to the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE MORNING SESSION AND DISCUSSIONS THEREON

GEOGRAPHIC HISTORY OF THE SAN JUAN MOUNTAINS SINCE THE CLOSE OF THE MESOZOIC ERA [1]

BY WALLACE W. ATWOOD AND KIRTLEY F. MATHER

(*Abstract*)

This paper gave a preliminary summary of physiographic studies which have been in progress during the last six field seasons.

At the close of the Mesozoic era and the opening of the Cenozoic era there were mountain-making movements which affected the entire Rocky Mountain province of North America, and the great dome which was then formed in the San Juan area was at once subjected to vigorous erosion. As the mountain mass rose erosion began, and as the great dome was more and more deeply dissected a mountain topography must have been produced, and those mountains may be thought of as the first generation of the San Juan Range. Certain deposits of Eocene till in this region indicate that during the dissection of these early San Juan Mountains ice formed in the range and descended to the bordering lowlands.

[1] Presented with permission of the Director of the U. S. Geological Survey.

After the retreat and disappearance of the early Tertiary ice, stream erosion continued, and the western portion of the San Juan Mountain area was reduced to a surface of slight relief which may be thought of as a peneplain. After the deposition of the Telluride conglomerate on this peneplain there was further erosion in the range, and then came the three great epochs of volcanism—the San Juan, the Silverton, and the Potosi. During these epochs of volcanism a great volcanic plateau was developed. By this time the Miocene epoch had been reached and possibly passed, and with the quieting down of volcanic activity began the erosion and dissection of the volcanic plateau. During this period of dissection another generation of San Juan Mountains was carved, this time out of volcanic debris and great lava flows.

The San Juan Mountains that were first carved out of this great volcanic plateau should then be thought of as surmounting those of today. Perhaps, if replaced, they would rise 3,000 or 4,000 feet above the present summits. They rose above the present summit peneplain.

With the redoming of the area, which involved the warping or doming of the summit peneplain, another cycle of erosion was begun. Valleys were again formed, and in these valleys snows collected which in time formed glaciers that advanced to the lowlands bordering the range. These earliest Pleistocene glaciers retreated and disappeared. The range continued to be uplifted, and the streams were so rejuvenated that they cut great canyons below the broad troughs occupied by the Cerro glaciers. Again, climatic changes favored the formation of ice among the summits, and that ice (the Durango glaciers) descended through the main canyons to the foothills and later retreated and disappeared. The canyons were still more deeply cut into the mountain mass, and then climatic conditions favorable for glaciation once more returned and the Wisconsin or third series of Pleistocene glaciers formed and descended through the great canyons, nearly as far as those of the Durango stage. These glaciers have now disappeared, and there is no true glacier ice remaining in the region today; but the streams are vigorously dissecting the mountain mass to still greater depths. The Black Canyon of the Gunnison has been largely cut during and since Pleistocene time. The vigor of the stream work is illustrated in many a sharp V-shaped notch cut below the depth of ice-action. High among the mountains are the remarkable landslides and great accumulations of talus.

The studies suggest somewhat continuous mountain growth in this region during late geologic time.

Presented in abstract extemporaneously by the senior author.

DOMINANTLY FLUVIATILE ORIGIN, UNDER SEASONAL RAINFALL, OF THE OLD RED SANDSTONE

BY JOSEPH BARRELL

(*Abstract*)

The old red sandstones of the British Isles have been commonly interpreted as deposited in great lakes. Walther has, however, urged that these formations are desert deposits; Goodchild regards them as laid down partly in large inland lakes, partly as torrential deposits, partly as old desert sands.

Extensive volcanic material is intermixed. The present writer interprets them as dominantly fluviatile deposits, formed under semi-arid climatic conditions. This stands between the extreme interpretations, but is essentially different from either.

The subject is important from the standpoint of general and historical geology, but perhaps especially from that of organic evolution, since these deposits contain the oldest well known fish faunas in contrast to the rare and fragmentary fossils of the previous periods. If the stratigraphic record is misinterpreted, there is given, in consequence, an erroneous conception of the habitat and life adaptations of the advancing evolutionary wave of the vertebrate phylum when it first clearly appears in the geologic record.

A reinterpretation must rest on the criteria as to the mode of origin of sediments as much as on the actual stratigraphic features. It is the matching of more recent criteria to the older known facts of the stratigraphy of the old red sandstone which makes the basis of this paper.

Presented in abstract extemporaneously.

Remarks were made by Messrs. A. W. Grabau and J. M. Clarke, with reply by the author.

INFLUENCE OF SILURIAN-DEVONIAN CLIMATES ON THE RISE OF AIR-BREATHING VERTEBRATES

BY JOSEPH BARRELL

(*Abstract*)

The relationships of ancient faunas to their environments is a field wherein paleontology and physical geology meet. It is a field which has been commonly cultivated by the former, but it is one in which the latter may as logically enter. It was as a physical geologist, with ideas sharpened and made definite by previous study of the nature of Devonian sediments, that the present writer took up this subject.

The Devonian formations indicate the general presence of warmth and seasonal rainfall. In the Upper Devonian the general climatic conditions became more markedly semi-arid. There is found to be a concurrent elimination of sharks from the fresh waters. As a result, dipnoans and crossopterygians come to dominate the fauna. It is apparently in the Upper Devonian, furthermore, that amphibians began to expand. An examination is made of the various possible causes for this advance in evolution. The only one which is found adequate is the compulsion of seasonal dryness.

The actual line along which air-breathing developed was only one of several possible lines. The directions and limitations of later evolution were, however, more or less determined by this choice. Slightly different conditions of environment and organic response, both readily possible, might apparently have been more favorable for the future of air-breathing vertebrates. By appreciating these lost opportunities of the remote past a better perspective is obtained, on the one hand, of the devious and groping and not always most successful nature of organic progress; a better appreciation, on the other hand, of the dangers of stagnation or extinction which have been happily passed by.

This and the previous paper were presented by the writer in abstract to the

American Society of Vertebrate Paleontology on December 26, 1907, but have been withheld from publication. The present presentation will place the emphasis on the more general aspects and consequences of the problems of the Devonian climates in relation to the rise of air-breathing vertebrates. It is intended to publish the papers in the near future.

Presented in abstract extemporaneously.

SOME LITTORAL AND SUBLITTORAL PHYSIOGRAPHIC FEATURES OF THE VIRGIN AND NORTHERN LEEWARD ISLANDS AND THEIR BEARING ON THE CORAL-REEF PROBLEM

BY THOMAS WAYLAND VAUGHAN[1]

(*Abstract*)

The ocean bottom off the shores of the Antilles shows three distinct types of profiles, and a fourth type is furnished by Saba and other banks. The first is that found off the volcanic islands, such as Saba and the members of the Saint Christopher Chain, into the sides of which the sea has cut relatively narrow platforms; but there are suggestions of submerged flats off the northwest end of Saint Eustatius and southeast of Nevis.

The second type of submarine profile is well represented off the north shore of Saint Croix and the south shore of Cuba. The precipitous character of these profiles indicates faulting, and the geologic structure supports this interpretation. There is a down-thrown block between the Virgins and Saint Croix and another between Cuba and Jamaica.

The third type of profile, represented by shores off which are extensive shallow flats, occurs where planation agencies have long been active. Here the rocks often, if not usually, dip under the sea at relatively gentle angles.

The fourth type of profile is represented by the extensive submerged banks or platforms which have no bordering lands and whose upper surfaces range in depth from 9 to 30 fathoms. Good examples are Saba Bank, southwest of Saba Island; Pedro Bank, southwest of Jamaica, and Rosalind Bank, off Mosquito Bank, which is the continental shelf northeast of Nicaragua and Honduras. That the depth of water on these banks is essentially the same as in many atolls of the Pacific, especially the Paumotus, has been repeatedly pointed out, but apparently the fact has not yet been sufficiently emphasized.

The third type of profile (that showing submarine terraces around islands) will now be discussed in some detail. From shoreline characters and other evidence the conclusion was reached that the Virgin Islands, the members of the Saint Martin group, and Antigua and Barbuda have recently undergone submergence to an amount of about 20 fathoms.[2] Assuming this conclusion to be correct, should the sealevel have remained stationary for a period of appreciable length antecedent to this submergence, there should be a submerged scarp or facet indicating its former stand; should there have been a succession of temporary stands, there should be a series of submarine terrace flats separated by scarps. The available sources of information were the charts of

[1] This article, illustrated by more than fifty profiles and a map, is published in the Jour. Wash. Acad. Sci., vol. 6, pp. 53-56, Feb. 4, 1916.

[2] Bull. Am. Geog. Soc., vol. 46, 1914, pp. 426-429.

the United States Hydrographic Office and of the British Admiralty. The Virgin Bank and the Saint Martin Plateau were selected for special study. The charts of the former, on a scale of slightly more than 1 mile to an inch, and that of the latter, on a scale of about 2½ miles to an inch, were contoured on a 2-fathom interval from the shore to a depth of 40 fathoms, and on an interval of 10 fathoms in depths between 40 and 100 fathoms.

The shoreline of the Virgin group shows indentations indicative of submergence, and that the sea has stood at its present level long enough for alluvial filling of the heads of harbor digitations, while sea-cliffs occur at the ends of promontories. The chart of the near-by sea-bottom shows that south of Saint John, Tortola, and Virgin Gorda there are two distinct submerged terraces and a less definite third terrace. The outer terrace flat lies at depths between 26 and 28 fathoms on its landward and between 28 and 30 fathoms on its seaward margin, and it ranges in width from a half mile to 3 miles. On its sea front is a ridge which is inferred to be a submerged barrier coral reef. On its landward side a scarp rises from a depth of 26 or 28 fathoms to about 17 fathoms. Above this scarp is a second terrace flat, which has a depth of 14 to 15 fathoms on its landward and a depth of 14 to 20 fathoms on its seaward face, and ranges in width from one-third of a mile to 2 miles. Apparently the outer margin of this flat also bears a coral reef. These are the two principal terrace flats. The scarp separating them is indicated by crowded contours, and chart number 1832, United States Hydrographic Office, shows its continuity for 36 nautical miles, or about 1½ land miles farther than from Washington to Baltimore. A third still higher terrace flat is suggested between depths of 6 and 10 fathoms, above which a fourth terrace may now be in process of formation, but the information regarding these is at present not definite enough to warrant a positive statement. The *continuity* of the upper one of the two well marked flats needs to be emphasized. It should be noted that east of Virgin Gorda there has been an uptilt.

On the windward side of Saint Thomas there is an extensive outer flat, bounded on its landward side by a steep escarpment which in places is nearly 160 feet high. The landward margin of the plain is between 26 and 28 fathoms in depth; the seaward margin has a depth between 30 and 34 fathoms; the width is as great as 10 miles and for distances as great as 8½ miles, in depths between 29 and 31 fathoms, the range in relief of the surface may be as small as 2 fathoms. Its outer margin is cut by reentrants which have bottoms about 40 fathoms deep and simulate hanging valleys. There are also near the outer margin of this flat banks or ridges, the upper surfaces of which are relatively flat, between 17 and 20 fathoms in depth. One of these banks has a total basal width of about 4 miles and a length of more than 5 miles. As its form is not that of a coral reef, it can only be the base of what was an island, which had been reduced almost to a smooth surface by marine planation and then, as indicated by other evidence, submerged. As all the other shoals, with one exception, are truncated at nearly the same level, it seems that most of them should be ascribed to a similar origin. These shoals usually show escarpments between 20 and 30 fathoms on their windward sides and more gradual slopes on the leeward sides. The outer flat on the north side of Saint Thomas corresponds to the lower flat on the south side of Saint John, Tortola, and Virgin Gorda. Both are submarine plains, which several lines of evidence

show were developed when sealevel was about 20 fathoms, or slightly more, lower than now. The escarpment extending from the islands north of Culebra Island, east of Porto Rico, across the Virgin Passage, and along the north side of Saint Thomas, and the escarpment on the seaward face of the outlying shoals apparently can be explained in no other way.

The indentations on the outer margin of the outer flat may have been caused by emergence and stream cutting after its formation, or they may be due to initial marginal irregularities which have not been obliterated.

The approximate accordance in level of the tops of the outlying shoals at depths between 17 and 20 fathoms has been mentioned. These summits accord in height with a flat or gently sloping zone, which lies above and nearer shore than the deeper flat and represents the 14 to 20 fathom flat south of Saint John and Tortola. It is scarcely represented on the seaward side of the promontories, namely, Cockroach and Cricket rocks and Outer Brass and Little Hans Lollick Islands. However, it spreads out on the flanks of the promontories and ranges from half a mile to nearly 1½ miles in width; it is separated on its seaward side by a steep slope or escarpment from the deeper flat and on its landward side by a less distinct escarpment, in places about 26 feet in height, from a less developed flat, which has a depth of 7 to 10 fathoms. The descent is sudden from the shore to about 6 fathoms, which is near the landward margin of the highest submarine flat. This flat also is narrow on the tips of the promontories mentioned, but widens on their flanks and along the shores of the main island. The submerged valley in Charlotte Amalia Harbor has a depth of 10 fathoms.

The narrowness or absence of the 14 to 20 fathom flat on the promontory tips, while it is so well preserved in protected places, especially off the south sides of Saint John and Tortola, shows that it is older than the deeper flat, and in exposed places was cut away during the formation of the latter, subsequent to the formation of which, after perhaps a brief interval of still lower stand of sealevel, the entire area has been resubmerged to an amount about the same as that of the initial submergence.

There is doubt as to the interpretation of the 7 to 10 or 12 fathom flat. In places it seems to be distinct and older than the one next lower, but it may represent the submarine terrace being formed at present sealevel.

According to the physiography of the sea-bottom, the Virgin Islands were joined to Porto Rico during the cutting of the scarp separating the deepest from the next higher flat. The biogeographic evidence shows conclusively that the two were united and have been severed in Recent time by submergence. Stejneger says in his Herpetology of Porto Rico: "It is then plain that the 16 species of reptiles and batrachians found in Saint Thomas and Saint John form only a herpetological appendix to Porto Rico." Doctor Bartsch informs me that the testimony of the land Mollusca is the same as that of the reptiles and batrachians. The biogeographic evidence substantiates the deductions based on the purely physiographic study.

There are three tiers of coral reefs in the Virgin Islands. They rise above (*a*) basements 10 fathoms or less in depth; (*b*) above the outer edge of the 14 to 20 fathom flat; (*c*) above the outer edge of the 28 to 34 fathom flat. As the escarpment within the outermost reef could not have been cut during the presence of such a reef, the flat must be older than the reef and the reef

must have developed during subsequent submergence. The flat, therefore, can not be due to the growth of the reef.

The members of the Saint Martin group have indented shorelines, sea-cliffs, and an unusually fine development of bay-bars. The relations on the windward side of the Saint Martin Plateau are similar to those north of Saint Thomas. The outer, deeper flat, from 26 to 36 fathoms in depth, has a maximum length, east and west, of over 30 miles. It seems composed of two terraces. The scarp on its landward side is distinct and in places is about 50 feet high, between 20 and 28 fathoms, as off the east end of Scrub Island, east of Anguilla Island.

As some of the submerged valleys on the east side of the Saint Martin Plateau resemble valleys in the Upper Cretaceous Anacacho limestone Texas, it appears that not only must the scarp line which has been pointed out be interpreted as a former shoreline, but that these channels with steep heads must be interpreted as former drainage lines which were subaerially cut and afterward submerged. The Anacacho limestone in the Brackett quadrangle is similar in general character to the limestone which composes Anguilla and Tintamarre.

While the shoreline stood some 20 fathoms lower than now, the Saint Martin Plateau must have been entirely above sealevel. The biologic evidence is in accord with this interpretation, but at present it alone is not sufficient to be decisive.

Antigua is another island with an indented shoreline. It shows typical instances of submerged valleys and fairly good examples of pouch-shaped harbors. Profiles off the southeast shore exhibit essentially the same features as the profiles on the Virgin Bank and the Saint Martin Plateau. If sealevel stood 20 fathoms below its present stand, Antigua and Barbuda would be united. Doctor Bartsch has especially studied the land mollusca and says: "The land shells show that these islands must have been connected in very recent time."

The deduction that there has been in Recent geologic time submergence to an amount of about 20 fathoms in the Virgin Islands, on the Saint Martin Plateau, and on the Antigua-Barbuda Bank, it seems to me, may be accounted demonstrated.

A set of profiles on the same vertical scale—(*a*) across Havana Harbor, showing depth of filled channel; (*b*) off the north side of Saint Thomas; (*c*) off the west side of Anguilla; (*d*) off the southeast coast of Antigua; (*e*) Mosquito Bank, off Nicaragua—all indicate a rise of sealevel by an amount of about 20 fathoms. There is in the Virgin Islands and in Cuba clear evidence of a lowering of sealevel by about 20 fathoms, perhaps more, previous to resubmergence. Although the evidence for the other areas is not definite as to the return of sealevel to a former stand, the similarity of the profiles suggests that it also occurred in them. As this lowering and subsequent rise of sealevel affects a large area, it appears too wide-spread to be explained by local crustal movement. The changes in position of strand-line here noted are more reasonably explained by the lowering of sealevel, due to the withdrawal of water in the Pleistocene ice epochs to form to great continental glaciers, and the raising of sealevel after each epoch through the melting of the glaciers; but the volume of evidence supplied by this area is perhaps not large enough

to justify a general conclusion as to relations of Recent coral-reef development to glaciation and deglaciation.

A brief comparison will now be made with the Great Barrier Reef of Australia. Fifteen profiles, on the same horizontal and vertical scales, the latter about 70 times the former, were drawn on the British Admiralty charts across the continental shelf south of the Great Barrier Reef and across the reef. These profiles show the continuity of the platform from the area south of the Great Barrier, that there is an outer, deeper flat about 200 feet deep, and that, except near its north end, the reef stands back from the seaward edge of the continental shelf. Therefore, apparently the idea that the platform was formed by infilling behind the reef may be permanently set aside. There is striking general similarity of the conditions presented to those off Nicaragua and in the West Indies. The evidence in favor of a shoreline between about 25 and 30 fathoms below present sealevel antecedent to Recent submergence is strong, if not conclusive, and supports the deduction that the living barrier reef is growing on what was a land surface in Pleistocene time—an interpretation essentially that proposed by E. C. Andrews in 1902.

The relations around the Pacific islands off which barrier reefs occur are those of continuous platforms surmounted or margined by discontinuous reefs. These relations indicate the superposition of reefs on antecedent platforms which have undergone geologically Recent submergence. E. C. Andrews so interprets the conditions of formation of the barrier reefs off the Fiji Islands.[3] It appears to me that the conditions governing the development of the living reefs in the West Indies, Central America, Brazil, Florida, and Australia are clear. The reefs have grown on antecedent basements during Recent submergence. The history of these basements is complex, but during Pleistocene time they stood higher with reference to sealevel than now; their outer margins were remodeled by marine cutting and marine planation, and they were then resubmerged. These changes in height of sealevel accord with the demand of the glacial control theory. It would be remarkable if the conditions in the tropical western Pacific Ocean were exceptional, and the present available facts indicate that they conform to the principles governing reef development in the other areas. Here it should be said, regarding the charts for the Pacific, that as they have been made primarily for navigation purposes, the depths of lagoons and lagoon channels are often given in a way fairly satisfactory, but on only a few charts can the submarine profiles outside the reefs be determined. The coral-reef problem can not be regarded as satisfactorily solved until the relations in the Pacific islands have been ascertained. In my opinion, but little further advance in understanding the problem can be expected from purely biologic studies or from physiographic investigations of the dry land surface alone. As apparently the greatest present need is for more accurate information on the detailed submarine relief in depths between 15 and 50 fathoms, especially on the seaward margins of the platforms, both outside the reefs and off the breaks in the reef lines, the efforts of those interested in such investigations should be concentrated on getting additional hydrographic surveys in coral-reef areas.

Presented by title in the absence of the author.

[3] Am. Jour. Sci., vol. 41, Jan., 1916, pp. 135-141.

CORAL-REEF PROBLEM

BY W. M. DAVIS

(*Abstract*)

The author, having reviewed various coral-reef theories preparatory to his Shaler Memorial voyage of 1914, and having visited on that voyage thirty-five reef-encircled islands in the Pacific, is now preparing a report on his observations and inferences. He finds in this connection only three theories that demand serious consideration—Darwin's theory of subsidence, Daly's theory of glacial control, and Vaughan's theory of submerged platforms. The present paper sets forth the difficulties that stand in the way of accepting two of these theories. The theory of glacial control seems inadequate because it excludes subsidence on insufficient grounds, because it assumes unwarranted conditions for preglacial islands, and because certain essential consequences of its main process—the truncation of low preglacial islands by the lowered and chilled ocean of the Glacial period—are not found on Pacific islands. The theory of submerged platforms is unsatisfactory because it assumes without sufficient warrant the origin of the platforms independent of coral agencies, because it assumes the absence of reef-building corals during the production of the platforms, because it provides no adequate cause for the production of flat platforms in close association with steep volcanic islands, and because it excludes all but small changes of level in reef-encircled islands during recent geological periods.

Presented in abstract extemporaneously.

Remarks were made by Professors R. A. Daly and J. P. Iddings, with reply by the author.

TERTIARY-QUATERNARY OROGENIC HISTORY OF THE SIERRA NEVADA IN THE LIGHT OF RECENT STUDIES IN THE YOSEMITE REGION[1]

BY F. E. MATTHES

(*Abstract*)

It is a noteworthy fact that the hanging tributaries of the Merced are not all graded with respect to the same former profile of the master stream. Those flowing over the massive and resistant granites of the Yosemite region indicate an old profile situated about 2,800 feet above the present canyon floor. Those flowing over normally jointed and relatively easily eroded rocks indicate a more strongly concave profile of a later date, situated 600 to 1,200 feet lower. The older profile of the Merced appears to be coordinate with the profiles determined by Lindgren for the Tertiary rivers of the northern Sierra Nevada (by means of the auriferous gravels). The younger profile of the Merced is believed to correspond to that stage of erosion which Lawson has recognized in the Chagoopa Plateau of the Kern River country. It clearly antedates the cutting of the inner gorge of the Merced, just as the mature valleys of the Chagoopa Plateau antedate the cutting of the Kern's narrow canyon. Inner

[1] Published with permission of the Director of the U. S. Geological Survey.

trenches of the same order occur in most of the great canyons of the western Sierra slope. Their youthful aspect, coupled with the fact that they are still actively being deepened by the rivers, points strongly to their initiation in consequence of rapid tilting at a time which can scarcely have been more remote than the beginning of the Quaternary period. The amplitude of this uplift at the eastern edge of the Sierra block may be roughly estimated from the inclination of the younger profile of the Merced. That profile appears at least four times as steep as a graded profile of the river might be expected to have been. It is to be inferred, therefore, that the range crest at the head of the Merced stood, prior to the last uplift, only one-fourth as high as it now stands. Mount Lyell, instead of 13,090 feet, had an altitude of only some 4,400 feet. This, it will be observed, is 2,000 feet less than the present altitude of Mono Lake (6,417 feet). It would follow, then, that the regions to the east of the Sierra Nevada have also been uplifted broadly by several thousand feet since the end of Tertiary time.

The Sierra uplift indicated by the older profile of the Merced is considerably less than that indicated by the younger profile and probably did not exceed 2,500 feet.

Presented in abstract extemporaneously.

The Society adjourned about 12.30 o'clock and reconvened at 2 o'clock.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE AFTERNOON SESSION AND DISCUSSIONS THEREON

The Society reconvened at 2 o'clock, with President Coleman presiding and Charles P. Berkey acting as Secretary, and took up the consideration of scientific papers.

GEOLOGICAL TRANSFORMATIONS OF PHOSPHORUS

BY ELIOT BLACKWELDER

(*Abstract*)

Phosphorus migrates widely in and upon the earth, passing meanwhile through a varied and interesting series of metamorphoses. An attempt will be made to outline these changes, beginning with the crystallization of apatite and other phosphates in igneous rocks and primary veins, following them through the circulation of ground-water to the ocean, there to undergo an all but endless series of reincarnations in the bodies of organisms, and ending temporarily with the fixing of the element in the form of phosphatic sediments. Subsequent changes take place in the latter, both near the land surface and in the deep interior of the earth. The various known types of phosphatic deposits may be placed rather definitely in this metamorphic cycle.

Presented in abstract extemporaneously.

DIFFUSION IN SILICATE MELTS

BY N. L. BOWEN [1]

(*Abstract*)

This paper gave a brief description of some determinations of the rates of diffusion of molten rock-forming silicates and a discussion of the significance of the results in petrologic problems.

Presented in abstract extemporaneously.

Discussion

Prof. J. P. Iddings remarked that Mr. Bowen's investigations were made on stationary liquids, but it is not to be supposed that large bodies of magma having different temperatures in different parts will exist without convection currents for any appreciable length of time, and his remark that convection currents may play a prominent rôle in differentiation processes is very much to the point. The effect of gaseous constituents in molten magmas, or of other components which reduce the viscosity of such liquids, must also be taken into account.

PETROGRAPHY OF THE PACIFIC ISLANDS

BY R. A. DALY

(*Abstract*)

The total number of named islands in the open Pacific is about 3,000. Of these, only 22 are reported to show outcrops of quartzose rocks. Five other islands are reported to have outcrops of crystalline schists, serpentine, or deformed limestone.

Excluding New Guinea and New Zealand with their immediate satellitic islands, Oceania has 345 islands which have been definitely described as wholly or largely volcanic in origin. Probably the whole number showing volcanic rocks above sealevel is at least twice as great. Among these islands only 152 have yet afforded any petrographic data, and not one has been examined with desirable thoroughness. To illustrate the scrappiness of our information as well as certain problems regarding the origin of Pacific lavas, the igneous-rock types of each island, so far as recorded, have been tabulated.

The compilation illustrates the advisability of a systematic exploration of all the smaller islands of the Pacific. The task is quite feasible, since the total land area involved is less than 75,000 square miles. If Hawaii, Viti Levu, Vanua Levu, New Pomerania, New Mecklenburg, and New Caledonia be excluded, the total land area to be covered would be only 50,000 square miles. In fact, with relatively small effort and cost, the natural history (including the petrography and geology) of all the land areas within one-eighth of the earth's surface could be investigated by a single organization. The Geological Society may well use its influence in developing a plan for such comprehensive exploration in the Pacific, under private American auspices.

Presented in abstract extemporaneously.

[1] Introduced by C. N. Fenner.

DISCUSSION

Prof. J. P. IDDINGS heartily approved of the proposition of Professor Daly regarding the systematic survey of the islands of the Pacific and suggested the desirability of having a properly equipped steamer for carrying out the survey.

Further remarks were made by Messrs. A. C. Lane and N. L. Bowen, with reply by the author.

SOME FACTORS WHICH AFFECT THE DEPOSITION OF CALCIUM CARBONATE

BY JOHN JOHNSON [1]

(Abstract)

This paper gave a brief discussion of the operation of the inorganic factors which affect the solubility, hence the precipitation of calcium carbonate, and therefore are important in connection with the origin and mode of formation of limestones. Of these factors there are two in particular, namely, the concentration of free carbon dioxide in the water and the temperature, which exert an influence more far-reaching than has hitherto been generally recognized; indeed, it appears that by considering their effects alone we are enabled to coordinate a large number of the phenomena of the deposition of limestones.

Presented in abstract extemporaneously.

Remarks were made by Dr. A. C. Lane, with reply by the author.

SPECIFIC WEIGHT OF DRILL CORES

BY ALFRED C. LANE

(Abstract)

It has been found that the specific gravity of drill cores, or volume per cubic foot, can be readily obtained by measuring their dimensions. This can be done to an accuracy of within 1 per cent, in pieces of core over 100 mm. long, without grinding off the ends, by using the micrometer gauge for the diameter and taking the average of six measurements of the diameter and the average of about four measurements of the length made with a finely graduated ruler. Thus, after weighing them, the weight in grams per cubic centimeter or (the same thing) ounces per cubic foot is obtained. Systematic tests seem to show that this may be of considerable practical value, as the variation in one lava flow between the denser, more crystalline, less glassy, and the more glassy, less crystalline, and perhaps more altered upper and lower parts, can be distinctly and continuously followed, even when the amygdaloidal or vesicular structure is not conspicuous.

Presented in abstract extemporaneously.

[1] Introduced by H. S. Washington.

CHEMICAL AND MINERALOGICAL COMPOSITION OF METEORITES

BY GEORGE P. MERRILL

(*Abstract*)

The paper gives a brief résumé of researches on the subject indicated by the title, which were made with especial reference to the reported occurrences of minor constituents. No traces were found in the stones and irons examined of antimony, arsenic, barium, gold, lead, strontium, tin, tungsten, uranium, zinc, or zirconium. On the other hand, the presence was shown, beyond an apparent reasonable doubt, of the rarer elements iridium, platinum, palladium, ruthenium, and vanadium. Comparisons are made between the meteorites and terrestrial rocks, consideration being given to the efficacy of the former as world-forming materials. A continuation of work, preliminary reports and abstracts of which have been published in the American Journal of Science and the Proceedings of the National Academy of Sciences, and final results of which are to appear in one of the memoirs of the Academy.

Read in abstract from notes.

Discussion

Prof. O. C. Farrington remarked that the long series of investigations on meteorites which Doctor Merrill had made had yielded many valuable results and were likely to yield more. To the list of elements found in meteorites given by Doctor Merrill it seems certain that radium can be added, since it has been found in one stone meteorite by an English analyst and is indicated by some unpublished results obtained in this country of which I had been notified. It has, so far, not been found in any iron meteorites. In comparing stony meteorites with the crust of the earth, I urged that the general average of stony meteorites could not properly be used, since most stony meteorites were of higher specific gravity than the rocks of the earth's crust. For the purpose of comparison, the class of stony meteorites known as eukrites should be used, since meteorites of this class most nearly resemble the rocks of the earth's crust in specific gravity and are composed of feldspars and pyroxenes, which are the dominant minerals in the earth's crustal rocks.

Doctor Merrill replied briefly to Professor Farrington's remarks.

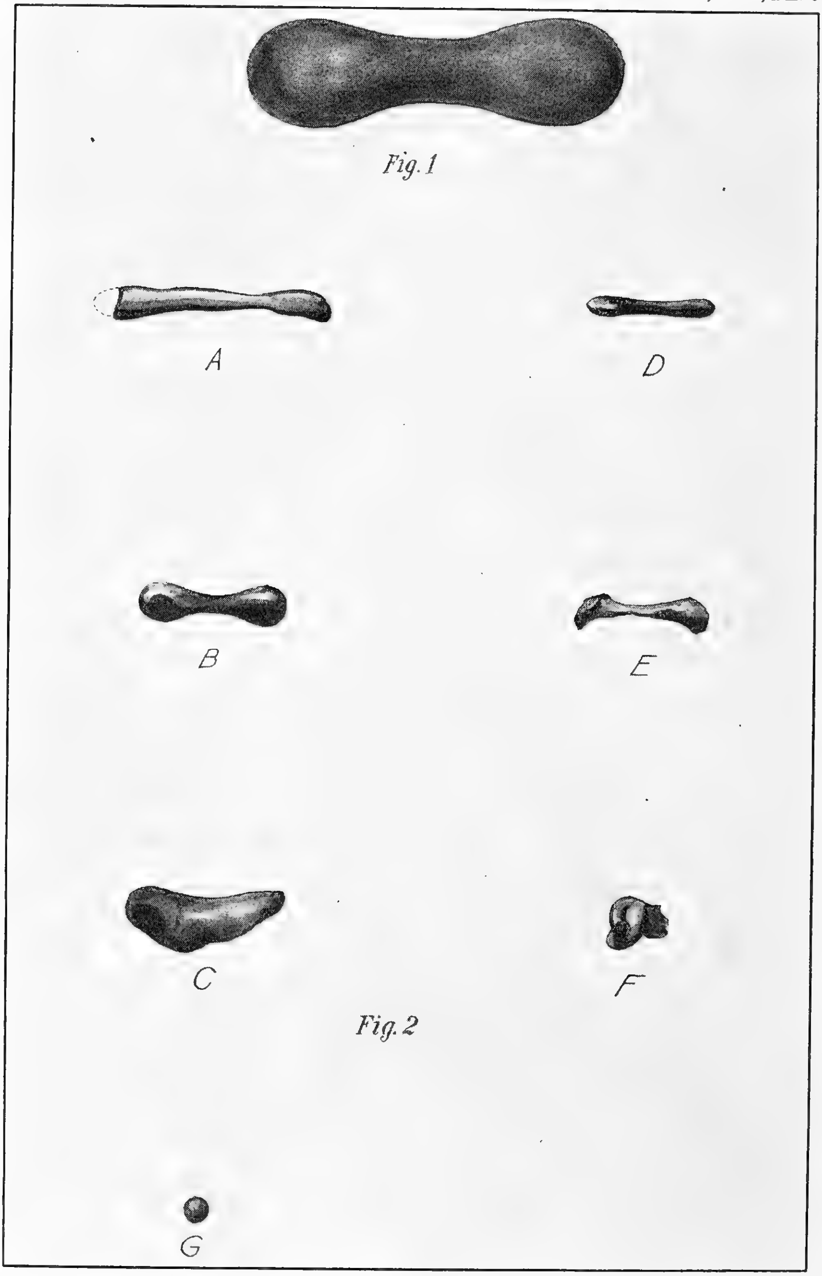
IMPORTANCE OF WATER AS A MAGMATIC CONSTITUENT

BY GEORGE W. MOREY [1]

(*Abstract*)

That water is an original constituent of the magma is now generally admitted, but the importance of its effects has not received adequate recognition. The erroneous assumption is often met with that, since the critical temperature of pure water is about 370°, it can exist, at temperatures higher than this, only in the gaseous state, no matter how great the pressure to which it

[1] Introduced by Henry S. Washington.



EXAMPLES OF AUSTRALITES

Figure 1 is a dumb-bell type of australite from Victoria, Australia. After Dunn. Figure 2, Plate V, Bulletin Geological Society of Victoria. 4/5 natural size.

Figure 2, A-G, are different forms of "Pele's Tears" from Kilauea, Hawaii. Enlarged three times. Drawn by Edw. C. Seibert.

is subjected. On the contrary, water can exist in solution in liquid magmas, and as such unquestionably plays a very important rôle in geologic processes which go on at temperatures up to 1,000° or higher. The presence of water in such solutions has three main effects, namely, it increases the fluidity of the melt, lowers the temperature at which crystallization begins, and facilitates the process of crystallization; these effects are marked even when the quantity of water is relatively small. These facts, which have an important bearing on certain phenomena of volcanism and igneous intrusion, were discussed and illustrated.

Presented in abstract extemporaneously.

Discussion

Prof. J. Volney Lewis: It is a well known fact that fragmental volcanics of acid character are far more abundant than basic ones. Some of us are accustomed to attribute this to the greater abundance of water in siliceous magmas, as a rule, or to their greater viscosity and hence greater resistance to the escape of this water during eruption. May it not be possible that the difference is in reality due, in part at least, to the greater capacity of basic magmas for retaining water in solution until it is gradually released by crystallization or imprisoned permanently in glass? I should be glad to know whether or not the investigation of which Doctor Morey has spoken might throw light on this question.

Doctor Morey replied briefly to Professor Lewis's remarks.

"PELE'S TEARS" AND THEIR BEARING ON THE ORIGIN OF AUSTRALITES

BY E. S. MOORE

CONTENTS

Introduction

Among the problems confronting the Australian geologists few offer more interesting material for speculation than the question of the origin of the australites. These peculiar bodies have been known by various names, such as obsidian buttons, obsidian bombs, and obsidianites. They somewhat resemble in composition and form the moldavites and billitonites, so Suess[1] has applied the name australites to such bodies from Australia, while he uses the term tektites to cover all bodies of this type.

It is not the object of this paper to go into a detailed discussion of the australites, as they have already been described very fully by several of the

[1] Franz Suess: Die Herkunft der Moldavite und verwandter. Gläser Jahrb. d. k. k. Geol. Reichsanstalt. Heft 2, vol. 50, 1900.

Australian and other geologists. Numerous analyses and a valuable discussion of the origin of these bodies will be found in a paper by H. S. Summers,[2] and an excellent set of figures accompanying a discussion of the genesis has been published by E. J. Dunn,[3] former Director of the Geological Survey of Victoria, Australia. In these publications various references to the bibliography on this subject will also be found.

Characteristics and Origin

The australites are small bodies of glass, often of remarkably perfect form, so perfect in some cases as to suggest an artificial origin. They are sometimes button-shaped, sometimes dumb-bell in shape, sometimes spherical, and at other times quite irregular in form. Many of them show flow structures and often pitted surfaces are developed. In chemical composition they are much like obsidian, although they are peculiar, in having in most cases a higher lime and magnesia content in proportion to potash and soda than is generally found in rocks so high in silica and in which the potash is usually higher than the soda. Summers, therefore, endeavors to show that they do not correspond to any terrestrial rock type. They are undoubtedly related to one another in chemical composition, as he points out, and most of them can doubtless be regarded as having a common source, yet comparison of the analyses with other special types show a close resemblance to some types of obsidian.

There have been advanced several theories to account for the origin of these peculiar bodies, the two main theories being the volcanic and the meteoric. The greatest difficulty so far confronting the volcanic theory is the distribution of the australites, which occur over a band stretching across Tasmania and over the whole of the southern part of Australia from the east to the west, covering the greater part of the island south of the tropic of Capricorn. Various suggestions have been made to account for their transportation, among them Mr. Dunn's ingenious bubble hypothesis, transportation by aborigines, emus, etcetera. These means have never appeared entirely satisfactory because, as pointed out by Summers, the australites are believed to be of Cenozoic age—although I believe they have never been found embedded in any solid formations—and that while there may be known volcanoes of this age in Victoria, some of the specimens are still found at least 2,000 miles from these volcanoes, and so far no deposits of obsidian have been found connected with them.

To account for the distribution, therefore, the meteoric hypothesis has been advanced, but this is open to as great objections as the other. In the first place, the composition, form, and internal structure of the bodies are quite different from those of known meteorites, and in the second place it seems hard to realize how such perfectly formed bodies, which give every indication of having been in a liquid condition, could strike the earth from some extraterrestrial source and have their outline so well preserved. If the heat which caused them to become liquid were due to atmospheric friction, it would be

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[2] H. S. Summers: Obsidianites—their origin from a chemical standpoint. Royal Soc. of Victoria, vol. xxi (new series), 1909.

H. S. Summers: On the composition and origin of australites. Report of the Australian Association for the Adv. of Sci., vol. xiv, 1913, pp. 189-199.

[3] E. J. Dunn: Australites. Bull. No. 27, Geol. Survey of Victoria, 1912.

greatest at the moment of impact and the body must certainly suffer deformation. On the other hand, if they had been heated, so that they could assume their present form before entering the atmosphere, it would be expected that the heat of atmospheric friction would cause the exterior to scale off and the perfect form to be destroyed.

Other suggestions concerning the genesis have been made by Gregory and G. P. Merrill. Gregory has stated that these bodies may have been due to lightning discharges in the great dust storms of Australia; but this theory has not received serious consideration, because it has neither the merit of satisfying the demand for distribution nor explaining the form and composition of the bodies.

In his article entitled "On the supposed origin of the moldavites and like sporadic glasses from various sources," after examining various obsidian pebbles, moldavites, and billitonites, Merrill concludes with the statement that "whatever may have been their original source, the Bohemian and Moravian specimens are now simply water-worn pebbles of weathered glass, originally etched by corroding vapors or solutions, the results being indistinguishable from those produced by artificial etchings on obsidian with fluorhydric acid. The Australian forms are likewise, to me, simply pebbles of glass which have been water-worn or abraded by wind-blown sands. In their contours there is nothing even suggestive of meteoric markings, nor do I find any semblance of such an origin, so far as the surface markings alone are concerned, in the examples from Billiton."[4] He explains, however, that this statement is not to be construed as meaning that he is opposed to the cosmic origin of these bodies.

Comparison with similar Bodies

Having thus briefly considered the australites, let us turn to some bodies of similar form whose origin is established beyond a doubt. There have been found two types of such bodies. One of these types, as mentioned by Mr. Summers,[5] has been taken from the smoke-boxes of locomotives, and the other is found near Kilauea, Hawaii, in the form of "Pele's tears." The latter are little masses of lava of various shapes, to which I believe Mr. Perret first applied the name "Pele's tears" because of their relation to Pele's hair and the tear-drop form of many of them. My attention was first attracted to these through the kindness of Dr. T. A. Jaggar, and they seemed to show such a marked similarity in form to certain of the australites that they may have an important bearing on their origin. So far as observed, they are confined to a small spatter cone close to the main crater of Kilauea. They vary from one-sixteenth to about one inch in length and in diameter according to the shape. They exhibit various forms. Such shapes as rings, half rings, pears, tear-drops, hearts, spheres, spindles, and dumb-bells are common. In one case an oval central body surrounded by a ring, which seems, however, to be more or less distinct from it, was found. They consist of a pumiceous dark brown glass, with a smooth glazed coating covering the surface of the body where the original surface is unbroken. A little evidence of flow structure may be seen on the surface in some cases, but no such perfect button forms as exhibited by some of the australites have been found (see figures).

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[4] G. P. Merrill: Proc. U. S. National Museum, vol. 40, 1911, p. 486.
[5] Loc. cit.

Several determinations for specific gravity were made and the results were found to vary considerably. Examples are 1.00, 1.25, and 1.36. In making these determinations it was desired to obtain the density of the body—that is, glass sponge with included air, rather than that of the glass composing the body.

Chemical Constituents

In order to determine whether these bodies represent a special differentiated phase of the magma, with greater silica content and higher viscosity or other particular properties, a partial analysis was made. The writer is indebted to L. J. Youngs, of State College, Pennsylvania, for the following figures:

	Per cent
SiO_2	49.94
Al_2O_3	13.52
FeO (total iron calculated as ferrous iron)	10.79
TiO_2	1.26
CaO	9.74
MgO	11.80
Total	97.05

There was a very slight gain on ignition. The alkalies were not determined, owing to scarcity of material on hand, but by difference they would correspond closely with amounts found by other analysts in rocks from this region. The rock is a basalt in composition, and under the microscope the crushed material is found to consist of 70 to 90 per cent of brownish glass, the proportions varying in different bodies, with small phenocrysts of feldspar and pyroxene and possibly some olivine.

A comparison of the analysis with various analyses of Kilauean rocks found in Washington's tables[6] and made by Silvestri, Phillips, and Lyons shows that the magnesia is very much higher and, as a rule, the lime is considerably higher than for most of these rocks. It compares better with an analysis of Pele's hair made by A. H. Phillips and is similar in most respects to an analysis by Merwin of the lava dipped from the crater Halemaumau.[7]

Although the figures obtained by Mr. Youngs were carefully checked and there seems to be an established high percentage of magnesia, it is not safe to draw conclusions, without further analyses, as to whether a high magnesia content is always characteristic of "Pele's tears." If it be a special feature, then may not their composition have some bearing on the question of the temperature at which this lava becomes liquid and possibly on the origin of these particular bodies? This point is more interesting because of the proportionally high percentage of lime and magnesia in the australites and the high temperature at which they dissolve and pass into the liquid condition. The calcium and magnesium bearing minerals, such as the olivines, pyroxenes, and more calcic feldspars, are always considered among the high-temperature minerals.

[6] Chemical analyses of igneous rocks. Professional Paper 14, U. S. Geol. Survey.

[7] Day and Shepard: Water and volcanic activity. Bull. Geol. Soc. Am., vol. 24, 1913, p. 586.

Conclusion

The forms of some of "Pele's tears" are so similar to the dumb-bell types of australites as to demonstrate the probability of the latter being of volcanic origin. These bodies of distinctly volcanic origin demonstrate the possibility of bodies with such shapes as spheres, dumb-bells, etcetera, being formed in the atmosphere from a rotating liquid body. There is no evidence in the composition of the lava that a specially viscous type of liquid is necessary to develop these forms; but the magnesia and lime contents are high, and it appears that we must look for some specially favorable condition of temperature, pressure, or other physical circumstance to account for their origin, since they are not, so far as known to the writer, common products of volcanoes. Thus may some special condition also have given rise to the australites.

No attempt is made here to throw fresh light on the distribution of the australites in Australia, although it is the opinion of the writer that they are of volcanic origin and the method of transportation will be discovered as the geology of Australia becomes better known.

TRIASSIC IGNEOUS ROCKS IN THE VICINITY OF GETTYSBURG, PENNSYLVANIA

BY GEORGE W. STOSE AND J. VOLNEY LEWIS

(Abstract)

CONTENTS

Distribution and Mode of Occurrence (by G. W. Stose)

The igneous rocks are all intrusive. No basalt flows. One main sill crosses the area from southwest to northeast just east of Gettysburg. Average thickness, 2,500 feet. Dips under shales on west at 20°. Irregular outline in places may be due in part to cross-faulting. Average width of outcrop about 1 mile. Local widening to over 2 miles, probably due to local thickening and corresponding displacement of overlying shale.

Two main cross-cutting bodies nearly at right angles to bedding. Larger one, 1 mile thick. Offshoots from these form minor sills and cross-cutting bodies.

A sill along the plane of the flat, overlapping western contact of Triassic sediments on Paleozoic limestone exposed at many places.

Thin dikes and sills are in part later than the large sill and cross-cutting bodies.

The igneous magma seems to have entered the Triassic rocks near their western border; to have spread along the flat, western contact as a sill; to have extended laterally in a thick sheet between the layers as the Gettysburg sill; to have broken across the bedding in several places between these two sills as cross-cutting bodies. Judging from the coarseness and thickness of the

intrusive bodies, the molten rock probably reached the surface, but all traces of the lava have been removed by erosion.

Petrography (by J. V. Lewis)

General Character

Dominantly diabasic. Remarkable diversity of differentiation facies. Range from coarse-grained granitic texture and pink to light or dark gray colors in the larger bodies to dense black rock in thin sheets and dikes and in contact facies.

Chief constituents greenish black pyroxene and whitish to gray plagioclase, the former generally preponderating. Approximately equal at many places and locally the feldspar is in excess. The microscope shows plentiful magnetite and minute apatite crystals and generally some quartz and orthoclase. Locally in darker varieties much hypersthene or olivine or both. In lighter facies quartz and orthoclase abound, chiefly in micrographic intergrowth. Here and there biotite and, far less commonly, titanite.

Pyroxene not uncommonly altered in part to uralitic amphibole or serpentine and chlorite with granular magnetite. Corresponding alteration of feldspars yields fine scaly (apparently sericitic) aggregates and, less commonly, kaolin. Epidote abundant in places.

Texture

Typically diabasic—pyroxene filling angular interstices in a felted ground-mass of slender plagioclase crystals. By coalescence of pyroxene into larger areas, in which feldspars are imbedded, the texture becomes ophitic. Dense varieties grade into typical basalt with glassy ground-mass; some with scattered phenocrysts of pyroxene and, less commonly, feldspar and olivine. In acid facies much quartz and orthoclase, in separate grains or micrographic intergrowth, occupy angular spaces among plagioclase crystals and there is much less pyroxene.

Order of Crystallization

Prevailing diabasic—plagioclase completed before pyroxene. Two marked exceptions: (1) Prismatic pyroxene crystals in some coarser quartz-orthoclase facies with subordinate plagioclase. (2) Pyroxene phenocrysts in dense black dikes, thin sheets, and contact facies, with few large feldspars. This earlier crystallization, probably before intrusion, followed the usual order in plutonic rocks and would have produced a gabbro. In the normal diabase the order has been: (1) apatite, (2) magnetite, (3) olivine, (4) plagioclase, (5) pyroxene, (6) micrographic quartz-orthoclase, (7) orthoclase, (8) quartz.

Varieties of Diabase

(1) *Normal diabase*, the most common pyroxene-plagioclase rock; (2) *feldspathic diabase*, or *anorthosite*, chiefly plagioclase feldspar; (3) *quartz diabase*, with abundant quartz, chiefly in micrographic intergrowth with orthoclase; (4) *micropegmatite*, mainly micrographic quartz-orthoclase; (5) *aplite*, essentially dense granular quartz-orthoclase rock; (6) *hypersthene diabase*, much hypersthene, replacing in part monoclinic pyroxene; (7) *olivine diabase*, with abundant olivine; (8) *basaltic diabase*, or *basalt*, dense black facies, in

places vesicular and having glassy ground-mass; (9) *olivine basalt*, dense black variety, with abundant olivine.

Presented in abstract extemporaneously by both authors.

DESERT REGOLITH AND ITS GENETIC RELATIONS TO MAXIMUM EPIROTIC DEPOSITION

BY CHARLES KEYES

(Abstract)

It was remarked by many who listened to the admirable illustrated lecture on the "Characteristics of Egyptian deserts," given by Dr. W. F. Hume before the meeting of the Twelfth International Geological Congress in 1913, that it was a very great surprise to learn that arid lands were so dominantly bare-rock plains rather than rolling sand wastes, or tracts deeply mantled by rock debris, as so commonly regarded. That the mantle of decayed rock materials which so widely distinguished most pluvial lands of the globe and which is so aptly denominated the regolith should appear to be so largely wanting in this most famous and typical of deserts was a fact that was directly ascribed to the peculiarities of arid land depletion.

The recognition of the prevalency of bedrock surfaces over broad tracts does not preclude the existence of frequent and often extensive accumulations of rock-waste in the deserts. Enormous amounts of these soil materials are manifestly not only constantly moved about over wide areas of the arid country, but they are directly exported far beyond desert confines. The areas of greatest accumulation of continental or epirotic deposits appear to have a close genetic relation to the areas of greatest arid deflation. Concrete illustrations are drawn from four continents.

Presented by title in the absence of the author.

ORIGIN OF FOLIATION IN THE PRECAMBRIAN ROCKS OF NORTHERN NEW YORK

BY WILLIAM J. MILLER

(Abstract)

It has been generally assumed that the Adirondack Precambrian rocks, including the Grenville strata and the syenite-granite intrusive series, have been severely compressed and folded as well as thoroughly metamorphosed and foliated by the compression.

Evidence will be presented to show that the Grenville strata have never been highly folded or severely compressed. Various broad Grenville belts are known to be only very slightly folded, while many masses, large and small, are merely tilted or domed at various angles, though some local contortions do occur. These structural relations are best explained as having been the result of slow irregular upwelling of the more or less plastic magmas (probably under very moderate compression), whereby the Grenville strata, previously deformed little or none at all, were broken up, tilted, and lifted or domed. Some bodies of strata, caught between batholithic magmas, were locally squeezed or contorted.

The Grenville sediments, which are thoroughly crystallized, were certainly reorganized into new minerals under deep-seated conditions; but, since the strata were never highly compressed, it is evident that they were subjected to essentially static rather than dynamic metamorphism. This explains not only the retention of stratification surfaces to the present time, but also the invariable parallelism of stratification and foliation.

Regarding the foliation of the syenite-granite series, it is believed that during the process of intrusion the magmas were under only moderate lateral pressure, if any; that the process of intrusion was long continued; that the foliation was developed essentially as a flow-structure, under moderate pressure, during the intrusion, and that the almost universal but varied granulation of these rocks was produced mostly by movements in the partially solidified magma, and possibly in part by moderate pressure applied after complete consolidation.

The usual parallelism of both Grenville masses and foliation with adjacent masses and foliation of the syenite-granite intrusives are readily accounted for because the Grenville masses were swung into general parallelism with the slow-moving magmatic currents.

Presented in abstract extemporaneously.

Discussion

Prof. J. E. Wolff: In the Archean highlands of New Jersey, with a nearly constant northeast striking and easterly dipping foliation and frequent northeast pitching linear structure, it seems necessary to suppose strong lateral compression.

Further remarks were made by Professors R. A. Daly, M. B. Baker, and George H. Chadwick, with reply by the author.

Professor Coleman remarked: It seems to me that both sides in this interesting discussion are entirely right, but in different areas. From my own field experience at one point or another I can corroborate the statements made by all who have joined in the discussion. There is no real contradiction between them, since what took place in one region differed from what took place in another.

LANDSLIDES IN UNCONSOLIDATED SEDIMENTS

BY DAVID H. NEWLAND

(*Abstract*)

The paper discusses landslides as an agency of degradation in regions of low relief and loose sediments like the larger stream valleys in the glaciated district. Occurrences in the terraced Pleistocene clay and sand beds of the Hudson-Champlain Valley are referred to in particular, on account of the number of available observations which extend over a considerable period of time.

Gravity disturbances in bedded clays and sands often occur on small gradients. The materials as a whole possess less stability under varying conditions of moisture content and climate than the unsorted heterogeneous ac-

cumulations of rock weathering that are commonly involved in slides in mountain regions. Their forms are correspondingly varied and complex, in some instances embodying very puzzling mechanical features. The gravity stress which is the fundamental cause of dislocation may be transmitted long distances through the medium of a practically fluid stratum below the zone of rupture, as has not infrequently happened in the Hudson Valley. Unlike the usual condition in mountain forms, there need be no essential variations in the character of the material displaced and the undisturbed beds. Any structural change that could be of significance in the formation of such slides, in the very nature of the case, is scarcely to be looked for, and the same is true also with respect to a slipping surface.

The conditions attendant on the disturbances can generally be determined by observation or by testing the ground in the vicinity, from which some conclusion may be drawn as to the causes leading up to the slides. The exact impetus or proximate causes, however, is seldom to be ascertained. Usually several factors have to be taken into consideration in determining the origin of individual slides, and their relative importance is difficult to estimate. The problem may be further complicated by the entrance of some external influence into the situation, either of natural development or arising from the agency of man.

Of the conditions which govern the form taken by the movement, those of more immediate concern are the nature of the beds—that is, whether clay, sand, or mixture of the two; the moisture content, and the surface contour. The forms that have come under observation in the Hudson Valley are as follows:

1. Surface creep, involving soil, sand, and gravel; little active in plastic clays.
2. Slumping and flows; peculiar to clays and silts.
3. Earth slides; materials of any sort, but not fluent; the movement takes place on the face of slopes that are oversteepened.
4. Subsidence of surface through squeezing out of a wet clay substratum on the plane of its bed.
5. Subsidence of surface from unbalanced pressure on confined liquid substratum, leading to an upward movement at a distance.

The influence of the various kinds of movement on the process of degradation is too important to be left out of account in a region like the Hudson Valley. Their importance, of course, can not be estimated quantitatively, although there is reason to believe that locally they have a predominant part in the work of surface leveling. On the nearly flat tops of the terraces erosion ordinarily is unable to make much headway, especially when the surface is heavily sodded, whereas a very light slope suffices to cause the precipitation of masses of earth in slides, some of which may attain large proportions. There is record of 10 or 12 catastrophic landslides in the Hudson Valley in a period of 75 years; the larger ones involved upward of 100,000 cubic yards of earth. The inconspicuous forms, no doubt, accomplish the largest share of leveling, since they are widely active with cumulative effects.

Presented in abstract extemporaneously.

The Society adjourned at 5.45 o'clock p. m.

ANNUAL DINNER

The annual dinner of the Society was held at Rauscher's, about 227 persons participating. Dr. John M. Clarke acted as toastmaster and the speakers of the evening were Messrs. William N. Rice, H. P. Cushing, Frank D. Adams, Charles D. Walcott, George O. Smith, W. G. Miller, and Joseph Barrell.

Session of Wednesday, December 29

The Society convened at 9.15 o'clock a. m., with President Coleman in the chair.

REPORT OF AUDITING COMMITTEE [1]

The Auditing Committee begs to report that they have examined the papers and vouchers of the Treasurer and find them to be correct and in good order.

The investment securities will be examined at a later date.

John E. Wolff,
George H. Perkins,
For the Committee.

The report was accepted.

The printed report of the Council was then taken from the table and, on motion, accepted.

The Society then took up the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE MORNING SESSION AND DISCUSSIONS THEREON

FERROUS IRON CONTENT AND MAGNETIC PROPERTIES OF THE NATURAL OXIDES OF IRON AS AN INDEX TO THEIR ORIGIN AND HISTORY

BY R. B. SOSMAN AND J. C. HOSTETTER [2]

(Abstract)

Practically all natural iron oxide contains more or less ferrous iron, the percentage varying from a few hundreths of 1 per cent up to the percentage found in magnetite. The magnetic susceptibility likewise varies over a very wide range and depends in part on the ferrous iron content. By measuring

[1] Under date of February 19, 1916, Edward B. Mathews reports that, acting as a member of the Auditing Committee of the Society, he examined the Society's securities in the hands of the Treasurer and found them to be as listed in the Treasurer's report under date of December 1, 1915.

[2] Introduced by Arthur L. Day.

these quantities, both for natural oxides and for oxides made under known conditions in the laboratory, it is possible to draw some conclusions concerning the conditions under which the natural oxides were formed or to which they have been subjected since their formation.

Presented in abstract extemporaneously by the senior author.

VARIABLE COMPOSITION OF MELANOCHALCITE

BY W. F. HUNT AND E. H. KRAUS

(*Abstract*)

Our previous knowledge of this rare mineral has been restricted to that of a single paper by the late Prof. G. A. Koenig. An investigation of recently acquired material shows, however, considerable variation in the chemical composition from that previously reported. Koenig's interpretation of the composition as a basic salt of an ortho-silico-carbonic acid is questioned, and evidence is given for considering melanochalcite as a mechanical mixture of tenorite, malachite, and chrysocolla.

Presented by title in the absence of the authors.

DEFINITION AND DETERMINATION OF THE MINERAL HYDROXIDES OF IRON

BY H. E. MERWIN AND EUGEN POSNJAK

(*Abstract*)

Specimens from a large number of localities were grouped according to optical characteristics. Those found to be sufficiently homogeneous were studied chemically and thermally. Definitions are based on a correlation of characters. Those characteristics most readily determined are emphasized.

Presented in abstract extemporaneously by the senior author.
Brief remarks were made by Prof. J. E. Wolff.

SALINE FUMAROLE DEPOSITS OF THE SOUTH ITALIAN VOLCANOES

BY HENRY S. WASHINGTON

(*Abstract*)

After a brief account of previous work on volcanic salts, the occurrences observed in the summer of 1914 at Vesuvius, Etna, and Vulcano were described. Analyses were given showing the characteristics of the salts found at each volcano. They present certain rather remarkable features—among them the practical absence of chlorides at Vulcano; the occurrences of thiosulphates (no sulphites) within the crater, but not on the outer slope at the same volcano: the prevalence of chlorides, with sulphates, at Etna; the relatively large amount of iron at Vulcano and its paucity at Etna, though the lavas show the converse relations. An interpretation of the results and their application to our views on the constitution of the magma was attempted. The purely

mineralogic description, in collaboration with Dr. H. E. Merwin, will be published later.

Presented in abstract extemporaneously.

CRYSTALS AND CRYSTAL FORCES

BY F. E. WRIGHT

(*Abstract*)

A general discussion of crystals as systems of vectorial forces, with special reference to their individuality and their behavior with respect to other systems of forces, special emphasis being placed on the individuality of crystals as it finds expression in the so-called false equilibria of thermodynamics. Methods for the measurement of crystal forces were considered briefly.

Presented in abstract extemporaneously.

EXTENSION OF THE MONTANA PHOSPHATE DEPOSITS NORTHWARD INTO CANADA

BY FRANK D. ADAMS AND WM. J. DICK

(*Abstract*)

The paper described an investigation undertaken for the Commission of Conservation of Canada for the purpose of ascertaining whether the great phosphate deposits recently discovered in Montana, Idaho, Wyoming, and Utah could be traced northward into Canada. Three lines of section across the Rocky Mountains in Canada were examined and were described. These are those on the North Kootenay Pass, the Crows Nest Pass, and on the main line of the Canadian Pacific Railway. In the most northerly of these sections, crossing the Rocky Mountain National Park at Banff, in the province of Alberta, the phosphate was discovered.

Presented in abstract extemporaneously by the senior author.

DISCUSSION

Mr. L. D. BURLING: The contact between the Devonian and the Cambrian in the North Kootenay Pass section was quite naturally ascribed by Dawson to faulting, but the direct superposition of the two systems described by Professor Adams is strikingly corroborated in three other widely scattered localities: (1) at Elko, British Columbia; (2) in the mountains near Upper Columbia Lake, and (3) along the main line of the Canadian Pacific Railway, just west of Banff, Alberta, where the Sawback formation has been shown to directly underlie the intermediate limestone of the Devonian and to be of Cambrian age; 25 miles to the west, however, the Cambrian is overlain by 10,000 or more feet of Ordovician and Silurian strata.

Of interest also in this connection will be the statement that the small "downfaulted block" which has been described as representing the "Jurassic" in the Canadian Pacific Railway section west of Banff is now believed to

represent an outcrop of the Upper Banff shale in its normal position with respect to the underlying Rocky Mountain quartzite.

The finding of the Albertella fauna in place is not the least interesting of Professor Adams' results. The reference of this elusive drift-block fauna to the Middle Cambrian instead of the Lower Cambrian has been confirmed during the past summer by its discovery in place in the type section on Mount Bosworth, British Columbia, some 700 feet above the base of the Cathedral limestone. The definite placement of this fauna is of value in connection with the discussion of the Precambrian age of the rocks of the Galton and Purcell series, since the latter are now known to be older than the Albertella fauna. That they are still older is evidenced by Dawson's early and hitherto unrecorded discovery of Lower Cambrian fossils in the Kootenay Valley south of Upper Columbia Lake.

Brief remarks were made by Prof. Alfred C. Lane, with reply by the author.

EMERALD DEPOSITS OF MUZO, COLOMBIA

BY JOSEPH E. POGUE

(*Abstract*)

The paper is a result of a field study of the deposits made in July, 1915. The geological and mineralogical relations of the emerald are discussed and evidence presented to show that the emerald originated as a result of gas-aqueous emanations from an intrusion that is not exposed, but is indicated by the presence of contact rocks, pegmatites, and a significant mineral association.

Presented in abstract extemporaneously.

CRYSTALLINE MARBLES OF ALABAMA

BY WM. F. PROUTY

(*Abstract*)

The crystalline marbles of Alabama are largely confined to an area about 35 miles long and 1¼ miles in maximum width. This area is for the most part a fault block, with the strike of its rocks in some places similar to and in other places differing from both that of the Ocoee phyllite, which bounds it on the southeast side throughout the length of the field, and the Knox dolomite formation, which bounds the field for the larger part of the distance on the northwestern side. Topographically the area is a well defined valley, except locally, where it is crossed by ridges of dolomite or more resistant rock.

Although there is no direct fossil evidence to indicate the age of the marble, the general characteristics lead to the conclusion that it varies in age from Cambrian to Ordovician in different parts of the field.

The thickest deposits of marble are in the central and southwestern parts of the field, and it is here that the chief developments of the area are being made at the present time.

The quarry methods employed in some of the openings are considerably

different from the usual methods in such work, the object being to take advantage of the unusual structural conditions.

The Alabama marble is medium to fine grained, with distinctly interlocking crystals. It is unusually translucent, sonorous, and resistant to abrasion and weathering. These qualities, together with its warm coloring, explain its growing popularity in the market.

A careful study of the structural conditions in different parts of the field show numerous examples of drag folding and, locally, schistosity in the marble.

The sharp line of demarcation between calcite and dolomite beds is suggestive of a distinct differentiation in the original sediments.

Presented by title in the absence of the author.

ORISKANY IRON ORE

BY R. J. HOLDEN

(*Abstract*)

This ore occurs in quantity only in Virginia. Its chief development has a definite stratigraphic position at the top of the Lewistown limestone. The ore bodies have thicknesses up to 40 feet and extend on the strike for distances of a few hundred feet to half a mile and down the dip for several hundred feet. Various theories of its origin have been given, but mining has shown that the ore is secondary, and it now seems certain that the most productive phase of the ore is a limestone replacement, the iron being derived from the overlying shale.

Presented in abstract extemporaneously.

GEOLOGIC MAP OF THE FORT HALL INDIAN RESERVATION

BY GEORGE R. MANSFIELD

(*Abstract*)

The sedimentary rocks of the Fort Hall Indian Reservation include representatives of all the great Paleozoic and later systems except the Cretaceous. Igneous rocks, mainly extrusives, are present in great abundance and considerable variety, including a single occurrence of nepheline basalt. Some of the Triassic and Jurassic rocks are so well developed as to require new subdivision. The structure is quite complex, with both folding and faulting, especially the latter, and there is an important thrust-fault, the Putnam overthrust. Three epochs of deformation and four of igneous activity have been recognized. There may be others. Important deposits of phosphate occur in the eastern part of the reservation.

Presented by title.

PRELIMINARY GEOLOGIC MAP OF THE WAYAN QUADRANGLE, IDAHO-WYOMING

BY GEORGE R. MANSFIELD

(*Abstract*)

The rocks of the Wayan quadrangle include some basalt and a long sequence of sedimentary formations representing all the great Paleozoic and later systems except the Cambrian and Silurian. The strata have been complexly folded and faulted. The most noteworthy structural features are the great bifurcated syncline that occupies the central portion of the quadrangle, bending off toward the northwest, and the Bannock overthrust that traverses the quadrangle in an irregular course. There are many minor folds and faults. Besides structural problems, there are many of stratigraphic and physiographic interest. The quadrangle is of great economic importance because of the large body of high-grade phosphate rock that it contains.

Presented by title.

GLACIAL LAKES AND OTHER GLACIAL FEATURES OF THE CENTRAL ADIRONDACKS

BY HAROLD L. ALLING [1]

(*Abstract*)

Although the glacial geology of the foothills of the Adirondacks has been investigated, the central area, specially the Mount Marcy, Lake Placid, Ausable, and Elizabethtown quadrangles, has not yet received the attention it deserves. Here Pleistocene phenomena are beautifully shown in great abundance. The most interesting features are two series of local glacial lakes, or water levels, ranging from 2,000 down to 500 feet in altitude through a dozen successive stages. They are indicated by deltas, terraces, strong beaches, and channels. In several of the outlets beautiful cataract plunge basins are exhibited. The post-lacustrine deformation of a number of the levels has been determined and indicates that the amount of uplift decreases in passing to the lakes of lower altitude.

Presented by title.

PLEISTOCENE FEATURES IN THE SCHENECTADY-SARATOGA-GLENS FALLS SECTION OF THE HUDSON VALLEY

BY HERMAN L. FAIRCHILD

(*Abstract*)

A map shows (1) the deep flooding by the sealevel waters of the Hudson Valley; (2) the vast areas of detrital plains; (3) the glacial indrainage, especially the Iromohawk; (4) the ice-block kettles of Saratoga and Round lakes.

The relation of the Iromohawk distributary channels to the Round Lake

[1] Introduced by H. L. Fairchild.

kettle shows that a large portion of the drift-buried ice block, which produced the basin of Round Lake, persisted until the locality had been raised 175 feet, the total Pleistocene uplift being 375 feet.

Differential uplift diverted the Iromohawk flow from its northward course, as mapped by J. H. Stoller, into the present Mohawk channel.

Presented in abstract extemporaneously.

PLEISTOCENE UPLIFT OF NEW YORK AND ADJACENT TERRITORY

BY HERMAN L. FAIRCHILD

(*Abstract*)

The paper published in the Bulletin, volume 25, pages 219-242, was intended to emphasize the fact of deep submergence in sealevel waters of the Connecticut and Hudson valleys. With further study of the marine plane and with precise levels on the international boundary, it is now possible to locate with approach to accuracy the isobases of land uplift across New York and the adjoining areas, east and west.

A fixed vertical relation in the Ontario basin between the Iroquois and the marine planes give us a key, for the Iroquois area, to (1) the amount of post-Iroquois uplift; (2) of Iroquois or glacial uplift; (3) of initial altitude; (4) of local warping; (5) of flooding, due to differential uplift of the Rome outlet.

The uplifting of the area, in time and amount, shows very close relation to the latest ice-body, and the uplifting appears to have been a progressive wave, subsequent to the far removal of the ice.

Presented in abstract extemporaneously.
Published in full in this volume.

Discussion on the two preceding Papers

Prof. J. W. Spencer: Some years ago I devoted much time in the study of the terraces of New England, but only published a note on them. From the highlands of northern New England extensive terraces, sometimes 20 miles long, were found to occur in all the great valleys, with slopes much less than the gradients of the rivers. These terraces descended not in warpings, but by steps (overlapping one another); not merely to the south in the Connecticut Valley, but westward down the Lamoille, eastward down the Saco, northward in the valleys leading to the Saint Lawrence. Consequently, if they were due to the rise of the mountain mass, there should be some agreement between the terraces of the different valleys. If such had been the case, the movements were per saltum in steps and not by warping curves. This does not support the hypothesis of Professor Fairchild, that the Connecticut terraces record the warping. Also long ago I found that the Iroquois beach extended east of Watertown, and correctly traced it to East Pitcairn; but in 1902 Professor Fairchild terminated late Iroquois some 20 miles within the explored zone, as shown on his map.

Prof. R. D. Salisbury: We can congratulate ourselves on the fact that Professor Fairchild has been able so long to follow up his studies on glacial

drainage and associated problems, and that he can now present to us the ripe conclusion of his long and careful study. The generalizations based on such detailed and long-continued work are the generalizations which we have come to trust. The fact that his conclusions tie up harmoniously the conclusions of many individual workers who have studied local areas intensively is gratifying and seems to be good evidence of the soundness of the results at which Professor Fairchild has arrived. I have but one comment to add. I think the east end of isobase O will have to be shifted somewhat farther south.

Professor Fairchild replied briefly to Professor Spencer's and Salisbury's remarks.

STUDIES OF GLACIATION IN THE WHITE MOUNTAINS OF NEW HAMPSHIRE

BY JAMES WALTER GOLDTHWAIT

(*Abstract*)

The field studied in 1915 is the northwestern part of the White Mountains, more particularly the Ammonoosuc Valley between Littleton and Bretton Woods. It is the purpose of the paper to show that glacial phenomena, which were regarded by Louis Agassiz and by Charles H. Hitchcock as records of local mountain glaciers, and by Warren Upham as records of a local White Mountain ice-cap, remaining at the close of the last Glacial epoch, are in reality records of the North American ice-sheet, which retired into Canada without leaving either mountain glaciers or a local ice-cap in its wake. Striæ, dispersion of boulders, terminal moraines, outwash plains and kame terraces, mapped in detail, are offered as evidence.

Observations on the Mount Washington Range, the Franconia Mountains, and Mount Moosilauke support the view advanced in 1912, that there were cirque cutting glaciers in the White Mountains at a time prior to the last regional glaciation, but that these glaciers were small and not very numerous.

Presented by title in the absence of the author.

GLACIATION AND STORMY PERIOD OF THE FOURTEENTH CENTURY

BY ELLSWORTH HUNTINGTON

(*Abstract*)

A recent study of the salt lakes at the eastern base of the Sierra Nevadas shows that their later strands can be dated in terms of the growth of the big trees on the other side of the mountains. Gale has shown that chemical evidence indicates that Owens Lake must have overflowed not more than "4,000 years ago or considerably less." Jones has shown the same to be true of Pyramid Lake. Since they did not use the entire drainage area and made no allowance for increased solution of mineral matter from the rocks with increased precipitation, it seems necessary to reduce the time to approximately 2,000 years. In that period Owens Lake has decreased to 40 per cent of its former size, and Pyramid has similarly shrunk, although not so much. Below the old outlet strands there is in each case a series of younger strands whose

height and relative age agree with the fluctuations in the growth of the sequoia trees 50 miles west of Owens Lake. The most notable strand appears to date from the fourteenth century—a time at which the big trees made a peculiarly rapid growth. It is remarkable for its size and strength. It could have been formed only under the influence of unusually high winds. What seems to be the same strand can also be recognized at Mono and Pyramid lakes, both by its relative location and its evidences of peculiarly strong wave action.

The fourteenth century period was also marked by climatic stress in other regions. In central Asia the Caspian Sea and Lop-Nor expanded with great rapidity, as is known from well authenticated historic records. In northwestern Europe storms of unusual severity afflicted the countries around the North Sea. Floods were of frequent occurrence, and extraordinarily cold winters caused the Baltic Sea to be frozen over completely. Norway suffered great economic distress because of persistent failure of the crops. In England the rains were so abundant that the average production of wheat per acre fell off one-third and the agricultural population was in great distress. In Iceland and Greenland similar occurrences took place. Petterson holds that increased severity of climate and the crowding down of the ice were the cause of the final abandonment of Greenland by the Norsemen.

It is noteworthy that in both the eastern and western hemispheres the chief evidences of climatic stress come from the semi-arid and desert regions, where a subtropical climate prevails, or else from the northern border of the belt of cyclonic storms. These are the regions where the Glacial period also produced the most noteworthy results, either by the expansion of salt lakes or by the production of ice-sheets. The conditions in the fourteenth century seem to have been of essentially the same nature as those of the Glacial period, the only apparent difference being in degree. It is possible that a study of such climatic fluctuations during historic times may lead to a final solution of the problem of the nature and cause of Glacial periods.

Presented in abstract extemporaneously.

PLEISTOCENE DEPOSITS OF MINNESOTA AND ADJACENT DISTRICTS

BY FRANK LEVERETT

(Abstract)

The extension of glacial investigations into Minnesota from districts farther east has shown that in the last, or Wisconsin, stage of glaciation the Labrador ice-sheet reached its culmination and began to wane before the ice which spread over northern Wisconsin and neighboring parts of Minnesota reached its culmination, and that this ice in turn began to wane before the Keewatin ice-sheet, which lay still farther west, reached its culmination. It is suggested in explanation of this westward wave of ice culmination that the highland of Labrador was the natural starting point of glaciation, and that because of storms coming to it from the southwest the ice-sheet grew westward to such an extent as to eventually receive more snowfall in the region south of Hudson Bay than in the Labrador district; so that there resulted a waning of ice movement from the latter district. Still later the ice-sheet grew westward into central Canada and caused the culmination of the Keewatin ice movement which spread into Minnesota and Iowa.

The same sort of westward growth of the ice-sheet may have taken place in the Illinoian stage of glaciation, for it now appears probable that the Illinoian drift from the Labrador center is somewhat older than drift which was carried southward from the region south of Hudson Bay through the Lake Michigan basin into Illinois, and also older than the Iowan drift brought in from districts still farther west.

This interpretation, if correct, may do away with some of the difficulty hitherto found in explaining the development of an ice-sheet in the low area west of Hudson Bay.

Presented in abstract extemporaneously.

Society adjourned at 12.45 o'clock p. m.

AFTERNOON SESSION

The Society met at 2.10 o'clock p. m., with Mr. F. B. Taylor in the chair.

RESOLUTION REGARDING THE TAKING OF EXPERT TESTIMONY

The Secretary *pro tem.* read a resolution adopted by the Council at its noon meeting as follows:

"In view of the fact that there is almost a universal desire among scientific men for some sort of reform in the manner of presenting expert opinion in legal procedure, and in view of the fact that the geologists of the country are certainly as deeply interested in this matter as any other scientific body, the following resolutions are presented for consideration:

"*Resolved*, That the Geological Society of America recognizes the urgent need of reform in the methods of securing evidence or expert opinion in judicial procedure;

"That the Geological Society of America approve the efforts of the American Association for the Advancement of Science in this behalf, and

"That the Council of the Society is hereby authorized and directed to coöperate with the Committee of the American Association for the Advancement of Science in an endeavor to bring about such a reform."

On motion, the resolution was adopted by the Society.

From 2.10 to 2.30 o'clock p. m. the Society met in joint session with the Paleontological Society and listened to the address of Dr. E. O. Ulrich, President of that Society, on "The use of fossils in correlation."

The Society then proceeded to the consideration of scientific papers.

Many of the attending geologists took advantage of the invitation of the Geophysical Laboratory to visit that institution during the afternoon. Arrangements were made by the staff of the laboratory to exhibit the work of the different departments, and a most instructive afternoon was spent by those interested in the geophysical and petrographic lines.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE AFTERNOON SESSION AND DISCUSSIONS THEREON

PENNSYLVANIAN OF TENNESSEE

BY L. C. GLENN

(*Abstract*)

The paper described briefly the formations into which the Pennsylvanian is divided in the State, gave their areal distribution, discussed the principal coals in each, and attempted to correlate these coals. Brief consideration was given to the age of the deposits found in the State.

Presented in abstract extemporaneously.

SUBDIVISIONS OF THE THAYNES LIMESTONE AND NUGGET SANDSTONE, MESOZOIC, IN THE FORT HALL INDIAN RESERVATION, IDAHO

BY GEORGE R. MANSFIELD

(*Abstract*)

A mineral examination of the Fort Hall Indian Reservation by a Geological Survey party in 1913 involved a detailed mapping of some of the Mesozoic formations. It proved desirable to subdivide the Thaynes limestone, Lower Triassic, and the Nugget sandstone, Jurassic or Triassic. The thickness of these strata, including the intervening Ankareh sandstone, is about 6,800 feet.

The Thaynes limestone was raised to the rank of a group consisting of three formations—the Ross limestone at the base, the Fort Hall formation, and the Portneuf limestone. The Ankareh, which at the type locality is a shale, was here found to be a sandstone. The Nugget sandstone was subdivided into four members—the Higham grit at the base, the Deadman limestone, the Wood shale, and the main sandstone member.

The paper described briefly the formations subdivided, explained the use of the names, and included a discussion by G. H. Girty of the interesting faunas of the three formations of the Thaynes group.

Presented in abstract extemporaneously.

STRATIGRAPHY OF SOME FORMATIONS HITHERTO CALLED BECKWITH AND BEAR RIVER, IN SOUTHEASTERN IDAHO

BY GEORGE R. MANSFIELD AND P. V. ROUNDY

(*Abstract*)

In the Montpelier and Wayan 30-minute quadrangles of southeastern Idaho, parties of the Geological Survey have found great thicknesses of strata, aggregating 17,000 feet or more, that have hitherto been assigned to the Beckwith and Bear River formations. On the maps of the Hayden Surveys both forma-

tions are included in the Laramie. The Beckwith has been assigned to the Cretaceous or Jurassic and the Bear River to the Upper Cretaceous.

There is a considerable lack of agreement, both lithologically and faunally, between the formations in the quadrangles named and the Beckwith and Bear River formations in their type localities. The discrepancy is so great that it now seems inadvisable to continue the use of the names Beckwith and Bear River in the district discussed. Three groups of strata are recognized, the lowest of which is marine Jurassic, and rests unconformably on the Twin Creek limestone, the main Jurassic formation of the region. The two higher groups are non-marine and probably Lower Cretaceous. They are separated from each other by an unconformity, but the lower group appears to be conformable on the Jurassic beds below. The two higher groups have some resemblances to the Kootenai of Montana and Canada, but the data are at present insufficient for their correlation with that formation. No characteristic Bear River fossils have been found in the district, though such have been found farther north, and there is a possibility that the doubtful beds may grade upward into the true Bear River in that direction.

The beds formerly called Beckwith are divided into seven formations and a new name is given to the strata hitherto called Bear River. The paper gave a statement of the stratigraphic problems involved, together with a description of the formations.

Presented in abstract extemporaneously by the senior author.

SEDIMENTATION ALONG THE GULF COAST OF THE UNITED STATES

BY E. W. SHAW

(*Abstract*)

Sedimentation along the Gulf Coast of the United States proceeds in three general and markedly different ways, each of which prevails over a large area. On the west coast the sediment delivered to the sea by streams is being reworked, some of it many times over, but is not carried far away. At the mouths of the Mississippi silt, clay, and fine sand are accumulating, layer on layer, almost precisely where dropped by the river. Along the Florida coast comparatively little sediment is carried into the sea by streams, and the littoral deposits consist largely of very clean sand and calcium carbonate extracted from sea-water by invertebrates, algæ, bacteria, etcetera.

The lagoon and barrier beach conditions which prevail along the west coast and a part of the north coast are perhaps the most common, and those at the mouths of the Mississippi most unique, though the processes in operation at the southern end of Florida differ in some respects from any in operation elsewhere in the world.

The object of the paper was to compare and contrast individual processes and results affecting each region. On shore and off shore samples of sediment from each of the three general regions were exhibited.

Presented in abstract extemporaneously.

RELATIVE AGE OF THE DETROIT RIVER SERIES

BY CLINTON R. STAUFFER

The Detroit River series is that part of the so-called Monroe formation which lies above the Sylvania sandstone. In an article on the "Nomenclature and subdivisions of the Upper Siluric strata of Michigan, Ohio, and Western New York," by Lane, Prosser, Sherzer, and Grabau,[1] this series was subdivided as follows:

Upper Monroe or Detroit River Series	Lucas dolomite Amherstburg dolomite Anderdon limestone Flat Rock dolomite

The series is overlain by the Onondaga (Columbus or Dundee) limestone or the lowest generally recognized Devonian of the region. Doctor Prosser originally defined the Lucas limestone as the upper portion of the Monroe and states that "it includes all the rocks between the top of the Sylvania sandstone and the base of the formation which Doctor Lane in Michigan has named the Dundee limestone."[2] It is thus evident that the Lucas has been much restricted in the later paper. However, it seems probable that the Upper Monroe, or Detroit River series, includes beds not very well known at the time the definition of the Lucas limestone was written. There is not only some doubt as to the stratigraphic order of these subdivisions, but very conflicting opinions regarding the real age of the whole series. It may be that part of the confusion lies in the fact that the faunas of these subdivisions are not entirely distinct, and that they have been mistaken for each other in the various outcrops. Only a small portion of any of the faunas of the series is as yet known.

The Detroit River series is rather widely distributed over Michigan, Ontario, Ohio, and doubtless Indiana as well. In Ohio the Anderdon outcrops in the quarries at Castalia; the Amherstburg probably occurs at Fremont, certainly at West Liberty, and the Lucas outcrops at numerous places along the margin of the Onondaga (Columbus), in northwestern Ohio. It is especially well shown and quite fossiliferous at Silica and Centennial, in Lucas County. In Ontario the most extensively distributed division of this series is probably the Amherstburg, at least so far as at present known. In addition to those along the Detroit River, outcrops of this dolomite may be found near Woodstock, Saint Marys, Wingham, Formosa, and McRae Point. The Lucas dolomite is less perfectly known, but appears to be represented in the outcrops at Kincardine and perhaps the upper part of the outcrop above Beachville. The Anderdon is not certainly known in Ontario, outside of Essex County, although it is quite well developed in Monroe County, Michigan. Probably the best development of the series is along the Detroit River, but it is by no means confined to that region. The salt shaft at Oakwood,[3] near Detroit, cut one of the best and most complete sections through it that is thus far known, excepting, of course, the numerous well records. But the most accessible sections are those that have been exposed in the vicinity of Amherstburg, Ontario.

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[1] Bull. Geol. Soc. Am., vol. 19, 1907, p. 556.
[2] Jour. Geol., vol. xi, 1903, pp. 540-541.
[3] Mich. Geol. and Biol. Survey, Pub. 12, Geol. ser. 9, 1911, fig. 21, opp. p. 278.

Figure 1.—The uneven upper Surface of the Anderdon Limestone in the Amherstburg Stone Company's Quarry

Figure 2.—Rough upper Surface of the Anderdon Limestone, showing Joints widened by Solution and later filled with Onondaga Mud

THE ANDERDON SURFACE AT AMHERSTBURG, ONTARIO

The Flat Rock dolomite is not exposed at Amherstburg, unless the lowest beds of the Amherstburg Stone Company's quarry belong to it; but the other divisions are well shown. These are all more or less fossiliferous and at certain places have yielded an abundant fauna. All divisions of the Detroit River series contain Devonian faunal elements. This is most marked in the Amherstburg dolomite, and probably least in the Lucas dolomite. The Amherstburg dolomite is typically developed in the bottom of Detroit River at Amherstburg, Ontario, and within the last seven or eight years this has been excellently exposed in the dry cut of the Livingston Channel. Near the north end of this cut the rocks are very fossiliferous and nearly all of the abundant forms are not only of marked Devonian aspect, but resemble decidedly the Onondaga fauna. Some of the most striking resemblances are to be found among the species of *Cladopora, Cystiphyllum, Favosites, Hederella, Romingeria, Synaptophyllum, Syringopora, Crania, Meristella, Pentamerella, Productella, Reticularia, Rhipidomella, Schizophoria, Spirifer, Stropheodonta, Conocardium, Modiomorpha, Paracyclas, Schizodus, Bellerophon, Callonema, Eotomaria, Loxonema, Platyceras, Tentaculites, Ryticeras, Dawsonoceras, Proetus,* etcetera. Such an aggregation of genera would alone be sufficient to demand comparison with the Onondaga fauna, but in many cases even the similarity of the species is so close as to have caused their identification with the Onondaga forms. Certainly one can have no quarrel with the man who insists that this fauna must be placed within the Devonian system. It is, in fact, a Devonian fauna. But the massive layers of brown dolomite containing this fauna are overlain, toward the south end of the cut, by similar beds carrying the Lucas fauna. A close study of this latter fauna, which is the one that has usually been considered to have especially strong Silurian affinities, shows that it is different from those to which it has been compared, and that the majority of its species, that have been considered Silurian, were really described from the Lucas dolomite of Michigan or from the Ohio outcrops of this same formation; 34 per cent of the species listed by Grabau and Sherzer[4] are also found in undisputed Silurian deposits; 9 per cent occur in typical lower Devonian, and 57 per cent are apparently not known outside of the Detroit River series. While the Lucas fauna at first seems impossible as a Devonian aggregation, this latter consideration decidedly minimizes the relationship to other known Silurian faunas.

In northwestern Ohio the Onondaga (Columbus) limestone rests unconformably on the Lucas dolomite, but at Amherstburg and at the Sibley quarry, nearly straight across the river in Michigan, it rests on the Anderdon limestone. The dip of the rocks at the Amherstburg Stone Company's quarry is to the west-southwest, although well records show that it evidently is reversed at no great distance. A similar dip occurs at the Sibley quarry across the river. In the dry cut of the Livingston Channel the dip is south at the rate of about 100 feet per mile, thus seeming to indicate the rising axis of an anticline of which the limbs slope away to east and west. This has led some men to the belief that the Anderdon belongs immediately under the Onondaga, as it has usually been found in surface outcrop. Also very serious doubt exists in the minds of some as to whether there is a stratigraphic break or an erosion surface at the top of the Anderdon limestone or between the Onondaga and

[4] Mich. Geol. and Biol. Survey, Pub. 2, Geol. ser. 1, 1910, pp. 211-213.

the Detroit River series. The question involved is not confined to the Detroit River region alone, but is contingent on observed conditions over the whole southwestern part of Ontario, as well as much of Ohio, and which conditions are undoubtedly similar to those in other adjoining States to the west. Near the eastern end of Lake Erie the relation of the Onondaga to the Silurian is one of unconformity (disconformity). This is well illustrated in the outcrops at Buffalo and to the westward in Ontario. There are, however, two distinct erosion periods represented at or near the base of the Onondaga. One of these preceded and the other followed the Oriskany sandstone.[5] It is probable that it was the latter of these that scattered the sands of Oriskany origin over a much wider region than that originally covered by the formation itself. This is indicated by the fact that none of the sandy remnants at the base of the Onondaga, west of North Cayuga township, in Ontario, carry even the slightest trace of Oriskany fossils. At most places a well developed basal conglomerate may be found in the lowest Onondaga beds, but occasionally it is rather imperfectly formed or sometimes entirely wanting. Even in such cases, however, not one of the Ontario contacts, and few, if any, of those in Ohio thus far examined, is without abundant evidence of the erosion period that intervened between the formations in contact. Near Springvale this is abundantly shown by the reworked beds of Oriskany, that now contain an Onondaga fauna, and the widened cracks in the pre-Oriskany dolomites, which are now filled with sand to a depth of several feet below the contact. At Goderich, Ontario, the basal conglomerate of the Onondaga limestone is especially well developed. Pebbles of the Upper Monroe as large as a man's fist are mingled with Onondaga corals, brachiopods, trilobites, etcetera, in an arenaceous limestone which rests on an uneven surface of Monroe. In the early days of the Goderich salt industry Mr. Attrill drilled a test well near the Lake Huron shore, across the Maitland River from Goderich. In reporting on the results of this experiment, Dr. T. Sterry Hunt says: "We now come to the consideration of an unexpected result of the examination of the cores from the Goderich boring, namely, the occurrence beneath 278 feet of beds, chiefly dolomite, which, according to the Geological Survey, underlie the Corniferous (Onondaga) limestone of the region, of not less than 276 feet, chiefly of gray, non-magnesian, coralline limestone, abounding in chert and seeming like a repetition of the Corniferous (Onondaga). Beneath this lower fossiliferous limestone, it will be noted, are dolomites with gypsum, succeeded by variegated marls, with an aggregate thickness of not less than 364 feet before reaching the saliferous strata, which latter have been penetrated 520 feet without reaching the underlying Guelph formation. Prof. James Hall, who has kindly examined such specimens of the corals as I have obtained from the limestone, recognizes in them two species of *Favosites*, *Favosites winchelli* and *Favosites emmonsi*, together with a section of *Acervularia* or *Diphyphyllum*."[6] This fossiliferous horizon is undoubtedly a part of the Detroit River series and very probably includes the Amherstburg dolomite and the Anderdon, as these beds outcrop about 35 miles farther north. The interesting point here is that it lies 278 feet below the base of the Onondaga, and that this latter has a well

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[5] Bull. Geol. Soc. Am., vol. 23, 1912, p. 373; also Geol. Survey Canada, Memoir 34, 1915, p. 60 and pl. iii.

[6] Geol. Survey of Canada, Rept. Prog. for 1876-1877 (1878), p. 242.

Figure 1.—Joints in the Anderdon Limestone widened by Solution and filled with Onondaga Mud

Figure 2.—Intersecting Joints in the Anderdon Limestone, showing later filling with Onondaga Mud

PRE-ONONDAGA JOINTING AT AMHERSTBURG, ONTARIO

developed basal conglomerate in which pebbles of the Detroit River series are mingled with sand and Onondaga fossils and which rests on an uneven surface of Detroit River series. Certainly there can be no doubt but that at this place the time interval between the fossiliferous Detroit River series and the overlying Onondaga was very long.

The most important consideration, however, is the condition at Amherstburg, since it is there that doubt has been expressed regarding the occurrence of an extensive unconformity (disconformity) at the base of the Onondaga. At Amherstburg the development of the basal conglomerate is weak; in fact, various geologists to whom specimens from this horizon were submitted expressed grave doubt as to the real conglomeratic nature of the deposit, although admitting the intermingling of the Anderdon and Onondaga limestones at the contact. This basal layer of the Onondaga is composed of more or less angular fragments of the compact drab Anderdon intermingled with the rather porous brown magnesian Onondaga, and in which there is sometimes so much sand that a thin layer might be called a real sandstone. In addition to the unevenness (see plate 7, figure 1), the upper surface of the Anderdon is rough and uneven. This roughness is attributable to differential weathering, since recently weathered surfaces of the Anderdon show the same pitted surface, although the rock is fresh at a small fraction of an inch below the surface. In some of these irregularities considerable accumulations of sand occur and fragments of the Onondaga often cling to these irregularities after the overlying layer has been removed. The Anderdon is affected by a system of joints which do not pass upward into the Onondaga. Some of these joints have been widened by solution to three or more inches before the Onondaga was deposited, and then into these cracks the Onondaga muds, intermingled with sand, filtered as the sea advanced over the region (see plates 7, 8, 9). In some cases this sand has penetrated several feet below the contact and may now be found in cavities among the Anderdon fossils. The upper surface of the Anderdon is often pretty well covered with rather large, low-spired gastropods and somewhat similar cephalopods (see plate 9). These are almost always of the brownish gray Onondaga limestone, which has led some one to suggest that the underlying mud must have been soft when the Onondaga sea advanced over it, and at which time these gastropods and cephalopods were pressed into this soft mud. Unfortunately these fossils are poorly preserved and have not been satisfactorily determined. Grabau and Sherzer say that the gastropod is probably *Trochonema ovoides*,[7] but they do not even mention the cephalopod. Possibly it is the *Trochoceras anderdonense* which they have described. The indications are that these gastropods and cephalopods were already fossil when the Onondaga sea advanced over the region; in fact, they were molds of the exterior and interior of the shells into which the Onondaga mud was pressed. Frequently it is possible to find casts of the shelly portion made up of the Onondaga material, which contrasts strongly with the other, while the internal mold of the Anderdon material is still retained and forms a perfect core for the fossil. Many of the infillings of these gastropod and cephalopod molds are in large part sand. One or two somewhat similar fossils were found in the basal Onondaga above the contact, but they were so poorly preserved that it was impossible to make out whether

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[7] Mich. Geol. and Biol. Survey, Pub. 2, Geol. ser. 1, 1909, p. 44.

they were in reality the same forms. These may have been internal molds loosened from the Anderdon and incorporated into the Onondaga at the time the latter was being deposited.

There is thus an accumulation of positive evidence demonstrating the existence of a period of erosion of long duration at the basal contact of the Onondaga in the Amherstburg quarry, and very similar evidences may be found on the Michigan side of the river. It is, of course, impossible to say positively that the sand at the contact represents the Oriskany in this region, remote from any known deposits of that formation, or that it is even material derived from the erosion of an Oriskany deposit, as is certainly the case farther northeast in Ontario. It is equally possible that the sand at Amherstburg was derived from outcrops of the Sylvania, subjected to erosion in pre-Onondaga time, since the Onondaga (Dundee) limestone is in contact with the Sylvania sandstone at the National Silica Company's quarry, 7 miles northwest of Monroe, Michigan,[8] and hence may have a similar relation at other near-by localities. It should be pointed out also that the Onondaga of extreme southwestern Ontario, like the Columbus limestone of northern Ohio, probably does not represent the whole of the formation as developed in western New York. In Ontario, immediately across the Niagara River from Buffalo, where the Onondaga limestone is probably the exact equivalent of the same deposit in New York, the lower layers are characterized by the relative absence of corals and the abundance of brachiopods. Some of the most characteristic fossils of this horizon are *Amphigenia elongata*, *Anophia nucleata*, *Anoplotheca camilla*, *Centronella glansfagea*, *Chonetes hemisphericus*, *Cypricardinia indenta*, *Platyceras dentalium*, and numerous others that are abundant at higher horizons. The beds carrying these species have been traced across the province and are last found near the shore of Lake Huron to the south of Port Elgin. These species are not found in the Onondaga at Goderich or at Amherstburg; neither are they found in the outcrops on the islands of Lake Erie and at Marblehead. The probability is that the beds which should contain them were never deposited in those regions, and that the lowest Onondaga is wanting. Some of these species reappear in the Columbus limestone of central Ohio, where the Onondaga fauna is again more like that of western New York.

It is therefore evident that the time interval represented by the unconformity (disconformity) between the Anderdon limestone and the Onondaga was a long one. If we may trust the record of the Goderich well, as described by Hunt, and the excellent section of the Oakwood salt shaft, the stratigraphic order as given by Sherzer and Grabau cannot be disputed. The period of erosion at Amherstburg therefore removed all the Lucas and Amherstburg dolomites and lasted through as much of the Onondaga as is represented by the lower zone of that formation at the eastern end of Lake Erie. The particular division of the Detroit River series which shows most marked Middle Devonian faunal characters therefore preceded its derivative fauna, the Onondaga, by the Lucas dolomite interval and this long erosion period. If the arenaceous material at the base of the Onondaga at Amherstburg and near-by localities in Michigan represents the Oriskany horizon, as believed by Sherzer

[8] W. H. Sherzer and A. W. Grabau: Geol. and Biol. Survey Michigan, Pub. 2, Geol. ser. 1, 1909 (1910), p. 40.

FIGURE 1.—THE SURFACE OF THE ANDERDON LIMESTONE, SHOWING MOLDS AND JOINTS FILLED WITH ONONDAGA MUD

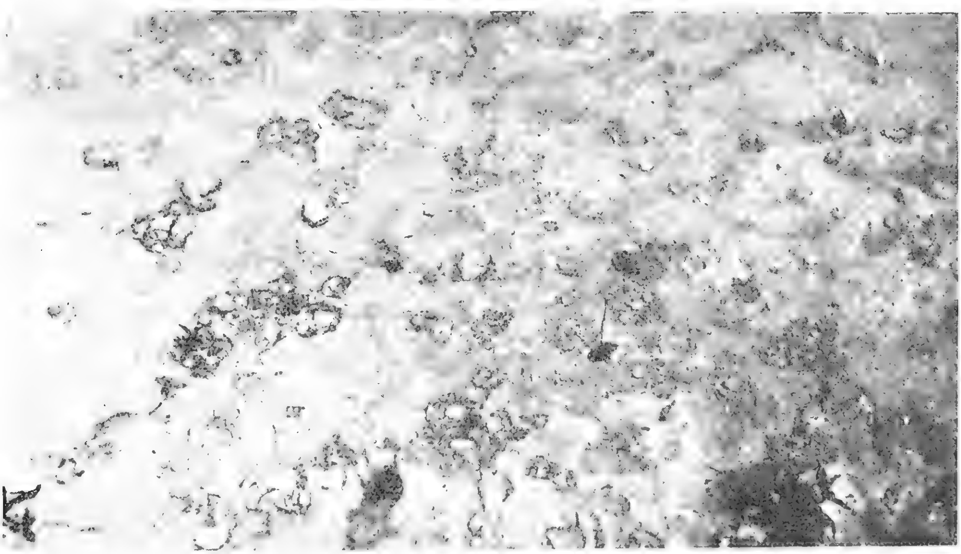

FIGURE 2.—UPPER SURFACE OF THE ANDERDON LIMESTONE, SHOWING ONONDAGA CASTS IN THE ANDERDON MOLDS

FOSSILIFEROUS SURFACES OF ANDERDON AT AMHERSTBURG, ONTARIO

and Grabau,[9] the Amherstburg dolomite can not very well be considered younger than Helderbergian. But since the basal Onondaga at Amherstburg does not carry the oldest fauna belonging to that formation, there is still room for doubt that the arenaceous contact is that representing the Oriskany farther to the east in Ontario and New York.

As is well known and as already pointed out above, the Oriskany sandstone itself rests unconformably on the Silurian (Cobbleskill and Rondout), at the eastern end of Lake Erie. It may be that the unconformity (disconformity) at the base of the Oriskany in western New York represents the one occurring at the base of the Detroit River series, and that the unconformity (disconformity) at the top of the Oriskany is the one so prominent at the base of the Onondaga in Ohio, Michigan, and extreme southwestern Ontario. If this be the case, these two unconformities run together at various places in Ontario near the eastern end of Lake Erie, but diverge rapidly to the westward from Springvale. There is thus represented an unknown interval during which it is probable the Detroit River series was deposited; for to maintain that such a fauna as that found in the Amherstburg dolomite is Silurian is more impossible than to find a place for it among the recognized Devonian formations. While the fauna of the Detroit River series is not altogether unlike that of the Helderbergian, it differs so markedly from it that it can hardly have lived in that sea which spread westward over New York and even into Illinois during Lower Devonian. The occurrence of some of these same fossils in the dolomites of Alberta, as shown by a small collection from the headwaters of the north fork of the Saskatchewan River,[10] suggests that there may have been another embayment from the north or northwest during early Devonian with a very different fauna from that found in the Helderbergian of the Atlantic embayment, although in part contemporaneous with it. The fact that a fauna similar to that of the Detroit River series, especially in its Mollusca, and to a less extent in the Anthozoa and Brachiopoda, occurs in the lowest Devonian of the Ural Mountain region of Russia[11] lends some support to this suggestion. Even in the Idiostroma limestone of the Cedar Valley of Iowa there is a suggestion of the recurrence, at a much later date, of the coral and hydrozoan reefs of the Anderdon.

Presented in abstract extemporaneously.

Discussion

Dr. A. C. Lane: Over a large area there is no trouble in drawing the line between Devonian and Silurian, as there is such an unconformity that the Onondaga (Dundee) comes almost directly, separated only by the Oriskany sandstone from the Salina or Lower Monroe. But near Detroit River we find that, while there remains an unconformity, or rather disconformity, under the Dundee, the Oriskany seems also to be almost or quite continuous as a transgression sandstone with the Sylvania sandstone. If we turn to Schuchert's

[9] Mich. Geol. and Biol. Survey, Pub. 2, Geol. ser. 1, 1909 (1910), p. 46.

[10] A. W. Grabau and W. H. Sherzer: Mich. Geol. and Biol. Survey, Pub. 2, Geol. ser. 1, 1909 (1910), pp. 102 and 116.

[11] Th. Tschernyschew: Mémoires du Comité Géologique, vols. iii, 1885, and iv, 1893. Von N. Lebedew: Idem., vol. xvii, 1902, tables opp. p. 132.

curves we see that between the marked depression of the middle of the (Upper) Silurian and the Devonian there was a long period of relatively low sealevel or high stand of the continent, not due to any disturbance in Michigan, but perhaps due to disturbances in the other hemisphere. The question is whether the base of the Devonian shall be drawn at the beginning or the end of this time of uplift. If we assume, as seems likely, that the beginning is the best line, the most sharply marked, and the one most nearly coeval throughout the world, then the Detroit River series would be Devonian.

We have, however, an alternation of a fauna so Devonian that it was at first taken for Hamilton (Traverse) and then a recurrence of Silurian fauna. But this Silurian fauna is of a local peculiar type—that associated with brines—that may easily be assumed to have lingered on in some Dead Sea or Aral Sea. The real difficulty is that in New York we have a Lower Devonian fauna of a quite different type. We must either assume these to have formed during the unconformity, so well described by Stauffer, or assume that New York and Michigan were in different provinces for a length of time that seems unlikely. But the division line between Devonian and Silurian must depend on diastrophic studies outside of Michigan.

RECESSION OF NIAGARA FALLS REMEASURED IN 1914

BY J. W. SPENCER

(*Abstract*)

In October, 1914, just ten years after my previous survey, which had been the fifth (the fourth was that of Kibbe, in 1890), I remeasured the crest-line of the main cataract of Niagara. The principal changes were not at, but adjacent to, the apex. Here had been a narrow V-shaped incision in the upper strata only, which has widened to one of U-shape 50 feet broad. To the west blocks of rock 400 feet long and from zero to 55 feet wide had fallen, thus straightening the line. The fallen area here and elsewhere aggregated about two-thirds of an acre, corresponding to a mean recession for the full width of the falls of scarcely 2.5 feet a year. The diversion from the river had been more or less compensated by the late prevailing high water. This reduces the mean annual rate of recession during 72 years to 4 feet a year, compared with 4.2 feet during the previous 62 years, but adds 5 per cent to the computed age of the falls.

The eastern end of the great cataract at the time of Hennepin (1678) has been investigated, the location of the western end having been previously found. Thus it appears that the mean rate of recession during 236 years was approximately 3.75 feet a year. This factor would increase the calculated age of the fall by 10 per cent, which figure still comes within the limit originally provided for (39,000 ± 4,000 years), but on the side of increased age.

Additional soundings in the upper part of the gorge were also made. In no case did I find depth of 100 feet, in contrast with those of 186 to 192 feet a short distance below. These confirm the evidence of a late reduction in the height of the falls, as previously described, and also mentioned by Kalm in 1750. The reduction in height was due to the falling of the gorge walls at the Whirlpool Rapids, thereby damming and raising the river level above them.

I made another sounding (of 210 feet) near that of 183 feet, previously de-

scribed, in the channel just beyond the end of the gorge. This shows that the level in Lake Ontario was, after the birth of the falls, even lower than I had previously announced.

These are new facts leading to further precision, besides confirming earlier results.

Presented in abstract extemporaneously.

TERRESTRIAL STABILITY OF THE GREAT LAKE REGION

BY J. W. SPENCER

(Abstract)

Among the results obtained by studying the lower lake terraces is one relating to the cessation of earth-movements. The terraces in question are those most strongly developed at or near the mouths of tributary streams, recurring all the way from the head of the lake to below the outlet of Lake Ontario, at 12 to 20 feet and 2 to 5 feet above its level. In them no deformation is determinable, in contrast with the differential movement of 540 feet between the head of the lake and Parishville, New York, as seen in the Iroquois beach, with tilting varying from 2 to 6 feet per mile. Having previously proved from the daily fluctuations of lake levels that there has been absolutely no earth-movement since 1854, these terrace features show that the cessation dates back a long time. The movements were in operation after the diversion of the Huron drainage to that of Lake Erie, which I have placed at 3,500 to 4,000 years ago. At present this would give near the date for their cessation.

Presented in abstract extemporaneously.

SCOUR OF THE SAINT LAWRENCE RIVER AND LOWERING OF LAKE ONTARIO

BY J. W. SPENCER

(Abstract)

I am not aware of previous investigations on this problem. When the waters of the Ontario basin were subsiding from the earlier glacial lake, the Saint Lawrence River channel did not come into existence until they fell to a level of not more than 20 feet above the present stage. This figure represents the total lowering of the lake due to the river scour acting on its general bed of drift. At the upper rapids the river has exposed very little rock. Thus at the first, or Gallops Rapids, the river flows over beds of boulders in two of its branches, while in the third the rock has been channeled for only a quarter of a mile (in Ordovician strata). These features show the relative youthfulness of the modern Saint Lawrence River. The present shoreline of the lake was examined for evidence of deformation, but neither in it nor the lower terraces could such be found.

To one who had primarily observed the coast of the lake at Hamilton and Toronto, where great beaches occur, he would be surprised to find how widespread has been the cutting away of the shores or the small development of the beach. It is much less developed than the Iroquois. Indeed, the interven-

ing terraces do not suggest such long pauses as were required for the building of the Iroquois beach. So far no time measurement is of any value. The most important problem is the date when the waters fell below the Iroquois beach, as this would most nearly coincide with the last days of the Glacial period. But these new data show the newness of both the Saint Lawrence and the modern shores of Lake Ontario.

Presented in abstract extemporaneously.

PLEISTOCENE DRAINAGE CHANGES IN WESTERN NORTH DAKOTA

BY ARTHUR G. LEONARD

(*Abstract*)

The continental ice-sheet produced important drainage changes in western North Dakota. Its effects are particularly well shown in the case of the Missouri, Yellowstone, and Little Missouri rivers, since all these streams were forced to seek new channels.

The southerly course of the Missouri River below old Fort Stevenson has been attributed to the later or Wisconsin ice-sheet, but evidence is presented that the valley is preglacial. This evidence is based on the presence of glacial boulders and drift on the valley bottom and at many points on a terrace representing a former floodplain of the Missouri. The river must have flowed in its broad, terraced valley at the time of the earlier ice-invasion, and on the floor of this valley the glacier deposited boulders and till. When the ice-sheet invaded the region, it blocked the valleys of both the Missouri and Yellowstone rivers, and also the preglacial valley of the Little Missouri, forcing these streams to seek new channels. Lakes were formed in the valleys of the Little Missouri and Yellowstone rivers, the waters rising until they overflowed the divide to the Knife River. The combined waters of the three rivers flowed east across Dunn County and southeast across Morton County to the mouth of the Cannon Ball River. The length of this Pleistocene valley of the Yellowstone and Missouri rivers, which extends from the head of the Knife to the mouth of the Cannon Ball and crosses the divides between the Knife and Heart rivers and that between the Heart and Cannon Ball, is 155 miles.

The lower 50 miles of the Yellowstone Valley was blocked with ice during the Glacial period, and the waters flowed east to the valley of the Little Missouri, forming at least two broad, flat-bottomed valleys connecting these streams. One of these valleys, 28 miles long, is now occupied in part by Bennie Pierre Creek, a tributary of the Yellowstone.

The Little Missouri was also forced out of its preglacial valley, which is now occupied by Cherry and Tobacco Garden creeks. It probably flowed for a time through the Pleistocene valley of the Missouri and Yellowstone rivers, but later took an easterly course and formed its present postglacial valley, which extends from the mouth of Bowling Creek to the Missouri River—a distance of 100 miles. Evidence is given that this lower valley of the Little Missouri is much younger than the portion above the mouth of Bowling Creek.

Read by title in the absence of the author.

LANDSLIPS AND LAMINATED LAKE CLAYS IN THE BASIN OF LAKE BASCOM

BY FRANK B. TAYLOR

(*Abstract*)

Lake Bascom was a sprawling glacial lake which filled the valley of Hoosick River and its branches in northwestern Massachusetts, southwestern Vermont, and adjacent parts of New York. The lake was 500 feet deep near Williamstown and slightly deeper toward Pownal. Many landslips have occurred around the sides of the main deep part of the lake and a few in ravines which held narrow bays. Laminated pebbleless lake clay and silt covers a considerable part of the lake floor around Williamstown and eastward toward North Adams, and it also occurs between North Adams and Briggsville and northward and at Petersburg and near North Pownal. During some of the later, lower stages of the lake, pebbleless clay and silt were deposited near Hoosick, around Hoosick Falls and North Hoosick and near North Bennington. Other laminated clays on the Owl Kill and on the Hoosick below Eagle Bridge are not related to landslips.

At its highest level Lake Bascom stood at an altitude of 1,125 or 1,130 feet above sealevel. With three or four exceptions, all the landslips observed in this region occur in the basin of Lake Bascom at some distance below its highest level. Some of the largest slips are very old, surely Pleistocene in age. In all probability they occurred soon after the fall of the lake waters. They are now represented by a series of steplike benches at certain places on the hillsides. Other slips are more recent and some are still in active movement. In one place they are just beginning, the bluff back of the edge of a previous slip being riven by deep cracks.

Nearly all of these landslips are related to underlying beds of laminated pebbleless lake clay and silt. The slips generally occurred on steep slopes where a stream was cutting at the bottom and where the underlying beds at or above the stream level were lake clay and silt. Some, however, are not related to any stream. The weakness of these beds, increased by softening in seasons of prolonged rain, caused a yielding and a slipping down of the heavy overlying masses. In some slips the laminated beds are partly exposed in vertical sections in the bluff at the back of the slipped mass; in others the clay beds are exposed in the banks or bed of the stream, where they are generally distorted.

A few landslips of a different character, perhaps more appropriately called landslides, occurred recently (August 20, 1901) on the east face of Mount Greylock. These were much smaller masses than some of the slips in Lake Bascom, but the amount of their descent was much greater, being in one case 1,500 feet. These slides occurred after a prolonged wet period and have no relation to lake clays.

Presented in abstract extemporaneously.

Discussion

Mr. George C. Martin stated that Lake Bascom was evidently very similar to some of the marginal lakes on the borders of the existing Alaskan piedmont

glaciers. These lakes are not only filled with icebergs, but in one case[1] a lake is known to contain a large arm of the glacier, which floats on the surface of the lake and forms the larger part of its area. The occurrence of till overlying the clays in the former bed of Lake Bascom may possibly be explained as the residue from the melting of a large amount of heavily debris-laden glacial ice that floated on the surface of the lake and that was left stranded on the lacustrine deposits when the lake was drained. The presence of many bergs and possibly of a floating glacial arm in Lake Bascom may also explain in part the poor development of beaches.

Further remarks were made by Messrs. M. B. Baker and H. F. Cleland, with reply by the author.

TYPES OF LOESS IN THE MISSISSIPPI VALLEY

BY B. SHIMEK

(*Abstract*)

The gray loess and two types of yellow loess of the Upper Mississippi Valley and the red and yellow loesses of the South are discussed with reference to geographical distribution, differences in structure, color, and fossils, and the significance of these differences. The conclusion is drawn that these types indicate in part differences in time of deposition and in part differences in source of materials. Incidental references are made to deposits which resemble loess and have been so classed.

Presented by title in the absence of the author.

Society adjourned at 5.20 o'clock p. m.

PRESIDENTIAL ADDRESS

At 8 o'clock p. m., at the Cosmos Club, Prof. A. P. Coleman delivered his address as retiring President, his topic being

DRY LAND IN GEOLOGY

Published as pages 175-192 of this volume.

The address was followed by the complimentary smoker given in honor of the Geological Society of America and the Paleontological Society by the local members of the former organization. The address of the President was the most largely attended session of the meeting, about 300 persons being present.

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[1] G. C. Martin: Geology and mineral resources of the Controller Bay region, Alaska. U. S. Geol. Survey, Bull. 335, 1908, pp. 47-48, pl. via.

Session of Thursday, December 30

The Society convened at 9.15 o'clock a. m., with President Coleman in the chair.

The Society proceeded immediately to the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE MORNING SESSION AND DISCUSSIONS THEREON

STAGES IN THE GEOLOGIC HISTORY OF PORTO RICO

BY CHESTER A. REEDS

(*Abstract*)

In March, 1915, Prof. C. P. Berkey in his report, "Geological Reconnoissance of Porto Rico," Annals New York Academy of Sciences, stated that an early Tertiary peneplain separated an "older" from a "younger" series of formations in Porto Rico. Observations made in the field during the following June and July suggest that more recent erosion cycles and periods of uplift and subsidence are also in evidence, and that they are responsible, for the most part, for the present configuration of the island. The positive and negative oscillations of the strand-line were induced in all probability by diastrophic movements within the island mass and adjacent sea-floor.

Previous to the early Tertiary peneplanation beds of shale, limestone, conglomerate, and volcanic rocks were intruded by igneous masses, producing a basal complex of folded and faulted strata and igneous intrusions. Following this peneplanation no igneous intrusion or ejectments have occurred, for none were observed in the basal lignitic shales and overlying chalky and cross-bedded limestones of the younger series. Folding and faulting are, however, in evidence in certain places in the beds of the "younger" series.

Evidences of marine transgression are to be seen in the marginal coastal plains and the wave-cut escarpments. Suggestions of an earlier transgression are to be seen in the even-crested cliffs and headlands on certain coasts and the isolated hills, ridges, and plateaus of near-by tracts. This older plain is typically developed in the district to the south and west of Yauco.

While successive transgressions and recessions of the sea were affecting the coastal and marginal tracts, subaerial denudation was busily sculpturing the present mature topographic features of the interior out of the exposed portion of the older warped peneplain and accompanying monadnocks. Features which indicate that stream erosion has been varied are to be found in the abandoned erosion levels in valley walls and at water gaps on rivers like the Descalabrado and the Jacaguas. At one stage the lower courses of these rivers were filled with sand and gravel. At the present time these sediments are being eroded and at some points the stream bed was observed to be 50 to 60 feet below the base of the gravel deposits.

The stages in the geologic history of Porto Rico were varied in length and kind of work performed.

Approximately 10,000 fossil specimens were obtained from the "older" and "younger" series of formations. In certain localities algæ, foraminifera, and corals were collected from the limestone members in the "older" series. They suggest Cretaceous age. The larger portion of the collection, however, was

STAGE	ELEVATION	EROSION	SUBSIDENCE	DEPOSITION	COMMENTS
XIV		Delta and Coastal Terraces		Coastal Barriers, Dune Sand, San Juan Formation River Flood Plains	Present
XIII	Slight Uplift	Rejuvenescence of Rivers			Partial Withdrawal of Sea from Platform
XII				Alluvial and Coastal Conglomerates, Sands and Shales	
XI			Marginal Transgression of the Sea		3d Cycle of Erosion incomplete
X		Inauguration of present Upland Dissection & Inception of present River Valleys			
IX	Uplift				Tilting Sedimentary Series, Folding & Faulting
VIII		Development of Peneplain			2d Cycle of Erosion incomplete
VII	Uplift				Tilting Sedimentary Series, Folding & Faulting
VI				Local Deposition of green Shales and Limestones	Long Duration
V			Subsidence affecting greater Portion of Island		Unconformity between "older" & "younger" Series
IV		Development of Peneplain		Deposition beyond Edge of present Platform	1st Cycle of Erosion
III	Uplift				Injected Porphyries, etc. affecting both Igneous & Sedimentary Series
II				Local Deposition of Conglomerates, black Shales, interbedded Tuffs, and Breccias, and Limestones on submerged Platform	Long Duration
I	Initial Volcanic Cones				

Chester A. Reeds, December 1915

FIGURE 1.—*Stages in the geologic History of Porto Rico*

gathered from the lignitic shales and white limestone of the "younger" series. The sea-urchins collected from these beds indicate late Eocene or early Oligocene age. It would be premature to assign ages to the various formations and stages in the geologic history of Porto Rico before this large collection of fossils has been worked up.

Presented in abstract extemporaneously.

Discussion

Mr. Edwin T. Hodge: The "older series" in Porto Rico has long been looked on as non-fossiliferous, and therefore of undeterminate age. Last summer, during my investigation in the south central portion of the island, I was fortunate enough to find some fragmentary fossils, which, it is true, do not constitute a whole flora or fauna, yet are sufficient to establish with certainty the following statements:

At the crest of the Sierra Cayey, the rocks of which lie near the base of the series, I found the calises of two *Cladophyllia furcifera* characteristic of the

Edwards of the Gulf. An adjacent bed of hematite contained some fossil leaves. These I have submitted to Doctor Berry and Doctor Knowlton, who tell me that while they are not critical, yet they tend to substantiate the evidence of the corals.

A few miles farther south and higher in the stratigraphic series, as worked out by purely structural methods, I found the lower portion of a *Venaricardia alticosta* index for the Chickasawan and Clairbornian of the Gulf.

The Cretaceous and Eocene strata in which these fossils were found have been folded to high angles—as much as 90° in places—and peneplained. The evidence of this peneplanation is decisive. It is shown by the even heights and flat crests of the mountains, the discordant relation existing between the drainage and the structure, which shows superimposition, and by the presence of deep residual soils.

On this peneplain was laid down the "later limestones." From fossils collected in Porto Rico by Doctor Berkey and studied by Miss O'Connell, we know these to be of Oligocene age.

Thus in Porto Rico we have positive proof that the Eocene is separated from the Oligocene by a period of time during which there was uplift and intense folding, followed by long erosion. This is entirely a new fact to science and throws light on the small thickness and extent of the Oligocene, both in the eastern United States and Porto Rico. It follows that the Oligocene present is probably very late Oligocene.

Doctor Reeds replied that as the collection was very large nothing definite could be said at present regarding the age of the beds.

CRETACEOUS OF ALBERTA, CANADA

BY JOSEPH H. SINCLAIR [1]

(*Abstract*)

Recent explorations by the author in the foothills of southern Alberta, Canada, have resulted in the identification of a very complete Benton fauna and accurate measurements of 4,500 feet of Cretaceous sediments.

The application of the Missouri River succession of Cretaceous rocks to the foothill district is questioned in several horizons, and Stebinger is borne out in his prophecy that the Clagett does not exist there as a lithologic unit.

The presence of the Bearpaw is also uncertain, although it may exist as a thin, brackish-water formation containing coal seams.

The adoption of the name "Dakota" for a thick formation lying between the Kootanie and the Benton is questioned on the ground that a not sufficiently great variation exists between the few specimens found in it by Cairnes and the flora of the Kootanie formation.

While the adoption of the section of the Missouri by Dawson may appear correct farther east in the Great Plains, it appears that continental conditions have pinched out certain marine phases of the eastern section, in the foothills of Alberta. The unsatisfactory line of demarcation between the Cretaceous and the Tertiary is also shown. Certainly no lithologic break is seen and the

[1] Introduced by Charles P. Berkey and A. W. Grabau.

lack of fossils makes a paleontological differentiation difficult. The total thickness of the Cretaceous appears to be 7,000 feet.

Presented in abstract extemporaneously.

SEDIMENTARY SUCCESSION IN SOUTHERN NEW MEXICO

BY N. H. DARTON

(Abstract)

In connection with the study of the Red Beds and associated strata in New Mexico many stratigraphic data have been obtained of the entire Paleozoic and Mesozoic succession. The distribution and local variations of the formations present some novel features which throw light on the geologic history of the region. Especially notable are the overlap relations of the formations of Carboniferous age, particularly the Pennsylvanian division, which overlaps Cambrian, Ordovician, Silurian, Devonian, and Mississippian rocks. The relations of the Red Beds of Permo-Pennsylvanian and Triassic age were studied in detail. Considerable new evidence was also obtained on the distribution of the Comanche group and overlying formations of Cretaceous age.

Read by title in the absence of the author.

DIVISIONS AND CORRELATIONS OF THE DUNKARD SERIES OF OHIO *

BY CLINTON R. STAUFFER

The youngest Paleozoic deposits in Ohio have long been known as the Upper Barren Coal Measures and more recently as the Dunkard series. These rocks are quite extensively developed in adjacent States to the east and have doubtless been removed by erosion over wide areas in which no trace of them now remains. It is only the comparatively thin western edge of the Dunkard that extends into Ohio and covers a rather narrow strip along the Ohio River from Jefferson to Meigs county. At the northern end of the Ohio portion of the Dunkard basin there is no appreciable break between the Monongahela and the overlying Dunkard series. From the stratigraphic relations the basal plant beds (Cassville) ought therefore to continue the same flora that flourished during the formation of the preceding Waynesburg coal bed, but apparently such is not the case. Over the southern half of the basin, however, the Waynesburg sandstone usually rests directly on the Monongahela with marked unconformity, the Cassville, the Waynesburg coal, and a portion of the underlying shales usually being absent. Unconformities in a series of rocks, such as the Dunkard, probably do not have any very great significance; in fact, they occur at several horizons within the series; but the development of the coarse massive Waynesburg sandstone, often a true conglomerate, over much of the unconformity between Monongahela and Dunkard may be indicative of changed conditions.

The Dunkard series of Ohio may be divided, as in Pennsylvania and West Virginia, into the Washington and the Greene formations. The former begins

* Published with the permission of the State Geologist of Ohio.

with the shales above the Waynesburg coal and ends with the Upper Washington limestone; the latter includes the remainder of the series. This division of the Dunkard series was originally suggested by J. J. Stevenson,[1] although, according to his definition, the Waynesburg sandstone and the underlying plant shales are included with the Monongahela series. The usage herein suggested for Ohio has been approved and used by the United States Geological Survey in the various Pennsylvania folios.[2] Each of the so-called Dunkard formations is made up of a great number of more or less distinct divisions, which are often traceable over very considerable areas and most of which have been given definite locality names by the Pennsylvania and West Virginia Geological Surveys. Many of these can be recognized in Ohio and form the basis of such stratigraphic correlations as is possible between the various parts of the Dunkard basin. This division of the Dunkard into two formations is very arbitrary, as the stratigraphical or even the lithological break at the horizon used is not pronounced. It does, however, mark the highest level at which marine or brackish-water fossils were found and probably represents the approximate close of the oscillations between land and marine conditions, and introduces the purely land and fresh-water deposits in the Dunkard basin.

The Washington formation varies in thickness from 230 feet in Belmont County to more than 300 feet in Washington County, while to the south of Marietta, where the massive sandstones are well developed, this division of the Dunkard includes 286 feet above the Washington coal, hence is probably at least 386 feet in thickness. The Greene formation reaches a maximum thickness of about 250 feet, although it is usually much thinner and often is a mere capping to the higher hills. Because of its limited distribution and its position in the hills, its character is less perfectly known than is that of the lower formation. Much of the topography of the region which it occupies consists of quite gentle slopes, which are covered with a deep soil and often well sodded.

From Marietta southward the dividing line between the Washington and Greene formations is hard to trace because of the absence of the Washington limestones, but it may still be continued by use of the Jollytown coal horizon or the base of the Jollytown sandstone, which probably marks the break between the two divisions. This sandstone stratum may be picked up at various places to the south of Marietta and has occasionally been quarried for grindstones.

A large part of the Dunkard of Ohio is to be classed as "Red Beds," although the Monongahela series and even the Conemaugh are not without their red shales, which in the Monongahela are often so like those of the Dunkard as to make them easily confused if it were not for other well defined strata associated therewith. There are but few really red sandstones, and those are usually only coated red on the outside or weathered surface, in the Ohio Dunkard. The red is thus almost confined to the shales. In the northern part of the Dunkard covered area the red beds are to be found chiefly in the Greene formation, but to the southward most of the shale in the whole series is red. In the main, these shales, sandstones, limestones, and beds of coal represent land and swamp or fresh-water deposits, but the presence of gypsum

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[1] Second Geol. Survey Penna., Rept. K, 1875 (1876), pp. 34-56.
[2] See U. S. Geol. Survey Folios Nos. 121, 180, etcetera.

in certain of the shales and sandstones, and again marine or brackish-water fossils in other beds, indicates that these conditions at times gave place to others of a very different character.

The Dunkard series as a whole is not very fossiliferous; in fact, it is almost as barren of the identifiable traces of life as it is of the workable coal seams, which originally suggested the term "Upper Barren Measures" for this deposit. In addition to the occasional plant fragment that may be found in almost any part of the series, there are certain rather well defined horizons in the Ohio Dunkard which have yielded important fossils. Plants are, of course, of first importance. Their remains are occasionally to be found in the roof shales of any of the coal seams or even in beds of argillaceous shale and sandstone. Almost any outcrop of limestone may be found to contain small fresh-water gastropods and ostracodes. The Middle and Upper Washington limestones often contain fish plates and teeth, some of which are referable to sharks, and are therefore probably marine. A *Lingula* occurs in the shales associated with the Washington coal. The lowest shales of the series are sometimes a black carbonaceous mass associated with a hard limestone, and these beds contain scales, teeth, and coprolites, all of which are probably fish remains. The most important find of the whole fossil collection, however, was made in the red shales of the Washington formation in the vicinity of Elba and Marietta. At the former of these places, near the base of the Dunkard, amphibian coprolites were found in relative abundance. These are remarkably similar to those found in the Permian of the Western States. At the latter place, during the past summer, fragments of a neural spine of *Edaphosaurus* were found in the sandstones associated with the red shales just above the Lower Marietta sandstone. The remains of this reptile have never before been found in the United States outside of Oklahoma, Texas, and New Mexico. The importance of this find must be very evident, since it agrees with the earlier conclusions drawn from identifications of the Dunkard flora and proves the age of the Dunkard to be identical with the Permian or Permocarboniferous of Texas. After having seen the whole vertebrate collection, Dr. S. W. Williston says that "of the fishes I recognize teeth like those of *Diplodus* from the Texas Permian, but this type runs through the Pennsylvanian and is not characteristic. The Elasmobranch spine is unlike any that I have seen in Texas. The coprolites can not be distinguished from those commonly found in Texas and New Mexico. . . . The *Edaphosaurus* spine is unquestionable, small as it is. The range of the family in Texas is both Wichita and Clear Fork. It occurs in New Mexico in the El Cobre beds, which the accumulated evidence now places as the equivalent of the lower Texas beds (Wichita). . . . In Europe *Edaphosaurus* occurs in the uppermost Carboniferous of Kuonova and the Rothliegende of Saxony." [3]

In view of this evidence of the Vertebrate fossils, there can be no doubt that the lower portion of the Dunkard series is the equivalent of the lower Texas beds (Wichita) which overlies the Cisco, and that in all probability both beds are Permian.

Presented in abstract extemporaneously.

Brief remarks were made by Prof. A. C. Lane.

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[3] Letter of December 15, 1915.

SILURIAN SYSTEM OF MARYLAND[1]

BY C. K. SWARTZ AND W. F. PROUTY

(*Abstract*)

The authors have been engaged in the study of the Silurian system of Maryland for several years and this paper presented a synopsis of their chief results.

The various formations that constitute the Silurian system of Maryland were discussed, including their lithology, faunas, and stratigraphic features. The formations were correlated with those of the same age in New York and other parts of the Appalachian basin. The problem presented by the Silurian Red Beds was considered briefly and certain analogies between them and the Catskill formation were pointed out.

Presented in abstract extemporaneously by the senior author.

Discussion

Mr. G. W. Stose: The stratigraphy presented by Mr. Swartz in the diagrams is no doubt more accurate and final than that in my report on the eastern part of the area about Hancock, Maryland. The interfingering of red sediments toward the east, extending to lower horizons than the base of the Wills Creek, is of special interest and will require careful study before final conclusions of nomenclature and correlation are reached.

In regard to the faunal relations of the Kiefer sandstone, I do not feel competent to speak; but Mr. Ulrich, who was responsible for having it made a member of the McKenzie formation in my report, has, in a recent table, placed it as a member of the Clinton formation, thus agreeing with Mr. Swartz.

Mr. George H. Chadwick: Objection is made to the inclusion of the Rochester in the Clinton. The distinctive Rochester fauna is widespread and the facts presented in this paper emphasize the undesirability of submerging it in the very different assemblage lying beneath it, against the plain evidence that the Rochester fauna endures with little modification into the Lockport.

HOMOCLINE AND MONOCLINE

BY REGINALD A. DALY

CONTENTS

Definition of "Homocline"

Workers in deformed strata have long felt the need of a general name for a mass of bedded rocks all of which dip in the same direction. Such a mass may be a tilted fault-block, a series of tilted fault-blocks, a combination of

[1] Presented by permission of the Director of the Indiana Geological Survey.

overthrust blocks, one limb of anticline or syncline, an appressed fold, a series of appressed folds, or a local, single flexure in a pile of otherwise horizontal beds. In many an instance the observer is long delayed in reaching a conclusion as to which of these or other categories a group of inclined beds is to be finally referred; after years of research he may not be able to make this decision. Yet in his field notes and reconnaissance report, if not in his final publication, he should have a broad term by which to refer to the structural unit here described.

Feeling this need during years of reconnaissance and detailed studies in the Canadian Cordillera and elsewhere, the writer has suggested the name "homocline" to cover the case.[1] A "homocline" is thus "any block or mass of bedded rocks all dipping in the same direction." According to one of its several definitions, "monocline" has exactly the meaning given to "homocline," and it is necessary to show reason for preferring the new term.

Different Definitions of "Monocline"

"Monoclinal" was invented by W. B. and H. D. Rogers, who wrote: "We propose the term *monoclinal* to signify a sameness in the direction of dip, and shall term a mountain or valley in which such sameness prevails a *monoclinal* mountain, or *monoclinal* valley."[2] Since sameness of dip, rather than the singleness of dip direction, is emphasized, it appears that "homoclinal" would have been etymologically preferable. Though the originators of the word, W. B. and H. D. Rogers made very little use of it, and then almost, if not quite, exclusively in the adjective form. Some authors have since employed "monoclinal" as a noun, equivalent to the proposed "homocline," signifying merely a series of beds dipping in the same direction; but "monocline" in this sense has been comparatively little used.

In 1865 Page used "monoclinal" as a noun, meaning a one-limb flexure, or the same as "monoclinal fold," Powell's name for well known flexures of the Colorado plateaus.[3] In 1880 Dutton adopted this usage.[4] In 1882 Dutton used "monocline" with the same meaning, and also in 1882 A. Geikie published what seems to be the first formal definition of "monocline." He expressed it in the following words:

"Curvature occasionally shows itself among horizontal or gently inclined strata in the form of an abrupt inclination, and then an immediate resumption of the previous flat or gently sloping character. The strata are thus bent up and continue on the other side of the fold at a higher level. Such bends are called monoclines, or monoclinal folds, because they present only one fold or one-half of a fold, instead of the two in an arch or trough."[5]

The Dutton-Geikie usage represents a considerable narrowing of meaning when compared with the "monocline" implied in the Rogers' use of the adjective "monoclinal." The same narrower definition of "monocline" is to be

[1] R. A. Daly: Memoir 68, Geol. Survey of Canada, 1915, p. 53.

[2] W. B. and H. D. Rogers: Reports of the Association of American Geologists and Naturalists, 1840-1842, Boston, 1843, p. 485.

[3] D. Page: Handbook of Geological Terms, Edinburgh and London, 1865, p. 312.
J. W. Powell: Colorado River of the West, Washington, 1875, fig. 67, opp. p. 183.

[4] C. E. Dutton: Report on the geology of the high plateaus of Utah, 1880, p. 26.

[5] A. Geikie: Textbook of Geology, London, 1882, p. 515.

found in all three of the succeeding editions of A. Geikie's textbook, in J. Geikie's Structural and Field Geology (1905), in the Standard Dictionary (1895), in Webster's New International Dictionary (1910), Murray's New English Dictionary (1908), in Norton's Elements of Geology (n. d., 1905 ?), Scott's Introduction to Geology (1911), in Blackwelder and Barrows' Elements of Geology (n. d., 1911 ?), and in Tarr and Martin's College Physiography (1914).

Several authorities define the adjective "monoclinal" in the sense of W. B. and H. D. Rogers—"dipping in one direction"—while defining "monocline" in the way adopted by Dutton and Geikie. Examples are to be seen in the Century Dictionary (1895) and in Murray's New English Dictionary (1908). J. D. Dana at first defined both "monoclinal" and "monocline" in the Rogers sense, but in the last edition of his Manual of Geology restricted the meaning of "monocline" as Dutton and Geikie had done.[6]

Among recent writers who have retained both "monoclinal" and "monocline" in the broad Rogers sense are: R. S. Tarr (Elementary Geology, 1897), Chamberlin and Salisbury (Geology, Volume I, second edition, 1906), Anderson and Pack (Bulletin 603, United States Geological Survey, 1915), and R. H. Johnson (Science, volume 42, 1915, page 450).

Favored Definition of "Monocline"

It is safe to conclude that the majority of influential authorities writing since 1880 have favored the Dutton-Geikie definition of "monocline." So far as the writer has been able to find out, Dutton had the priority in the use of this word in geology, while A. Geikie seems to be the first to have given it formal definition. Therein lies one reason for retaining this usage.

A second and stronger reason is found in the need for the word in just the sense implied by Dutton and expressed by Geikie. For the observer working in Arizona, Dutton's "monocline" is as necessary as "anticline" is for the worker in Pennsylvania. In general, the geologists who are interested in a simple, ultimately complete system of names for all types of folds may well favor the Dutton-Geikie usage. The use of the noun in that sense makes obviously desirable a similar narrowing of the adjective "monoclinal." This seems to be a compelling argument for disregarding priority in connection with "monoclinal" and for re-defining it so as to cover one instead of many kinds of structure in bedded rocks.

French and German authors have long used the word "flexure" (Flexur) to signify "monocline" in the Dutton-Geikie sense. This usage was introduced by Suess and followed by Richthofen, de Margerie and Heim, Reyer, Neumayr, Credner, de Lapparent, and Haug. It is, however, impossible for writers of English to limit "flexure" in this way. The word has too long meant "folding" in general, or simply "fold," as in the writings of the Geikies, Prestwich, Jukes Brown, W. B. and H. D. Rogers, Dana, Dutton, Willis, and others. Suess proposed the restriction of meaning because the monoclinal fold (a result of tension and radially acting force) was thought to be genetically and thoroughly contrasted with anticlines and synclines (results of compression and tangential

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[6] J. D. Dana: Textbook of Geology, 1864, p. 42; New Textbook of Geology, 4th ed., 1883(?); Manual of Geology, 4th ed., 1895, p. 102.

force). Yet some structures, correctly described as synclines and anticlines because of their arrangement of dips, are probably due to forces acting radially and not directly parallel to the earth's surface. In any case, it seems better, as far as possible, to keep all these elementary terms purely empirical in meaning and free from theoretical connotation.

Summary

Thus simplicity, the demands of a logical system, the active need of field geologists, and a certain degree of priority suggest that Dutton and Geikie should be followed in their definition of "monocline." It may be noted that de Margerie and Heim recommended the noun "monoclinal" as a synonym for the continental word "Flexur," or "flexure."[7] Hence there appears to be no reason why French and German writers should not aid in internationalizing the nomenclature here advocated.

If "monocline" and "monoclinal" be fixed in the Dutton-Geikie sense, the broad, useful concept denoted by the "monoclinal" of W. B. and H. D. Rogers needs a new name. As already observed, that term is readily found by following literally the Rogers recipe for its manufacture. They intended to name a body of strata showing throughout dip in the *same* direction and for that "homocline" (or "homoclinal"; adjective, "homoclinal") is the appropriate word. Its use would have the advantage of rescuing "monocline" from its threatened fate of meaning two different things, and therefore meaning neither without cumbrous explanations. In stratigraphic, physiographic, economic, and even philosophical geology "homocline" should be distinctly useful.

Presented in abstract extemporaneously.

Discussion

Mr. G. W. Stose: I welcome the suggestion of the term homocline. The need of a term for this structure has long been felt in the United States Geological Survey, where confusion has been avoided in editing by using *monoclinal* for the homocline as distinct from *monocline* or monoclinal fold. The term homocline will not only be useful in referring to rocks having the same dip, but whose structure is not known, as mentioned by Professor Daly, but also for the beds between an anticline and syncline, to which neither the term limb of the anticline nor limb of the syncline is not appropriate.

Prof. William H. Hobbs: I wish to add my indorsement of Professor Daly's position and express the belief that the use of homoclinal in the sense of uniformity of dip will prevent much misunderstanding. A region where such a term might have been used to advantage is that of the Taconic shales in eastern New York State. Almost by accident I came on much compressed anticlinal cores in a number of localities which showed the wide zone of westerly dipping shales to be isoclinal, though before regarded as a single limb of a fold.

[7] E. de Margerie and A. Heim: Les dislocations de l'écorce terrestre. Zürich, 1888, p. 26.

OCCURRENCE OF INTRAFORMATIONAL CONGLOMERATE AND BRECCIA

BY F. V. EMERSON [1]

(Abstract)

Areas of round clay pebbles and angular masses of stratified clay appear in the sands and sandy clays of Eocene age near Shreveport, Louisiana. The rounded pebbles are of sandy clay, soft when wet, but fairly firm when dry, and of diameters up to 3 inches. Many pebbles are incrusted with iron oxides, forming concretionary masses. The clay fragments are mainly tabular, but occasionally there are large masses of stratified and often well-jointed clay which stand at all angles. The matrix is a rudely stratified sandy clay, in places strongly cross-bedded.

The rounded pebbles indicate weak wave action in waters of moderate depth and the clay breccias with their disordered arrangements show sliding and slumping.

Presented in abstract extemporaneously.

Brief remarks were made by Messrs. A. C. Lane and A. P. Coleman.

KEWEENAW FAULT

BY ALFRED C. LANE

CONTENTS

Summary

The Keweenaw fault began as a block-fault in an interior basin like those of the Great Basin region and was also a line of volcanic activity (figure 2).

The Upper Keweenawan were deposited as playa beds in the trough *d* and shade into the "Eastern" Upper Cambrian sandstone, and that perhaps into the "Trenton" limestone. Thrice later—in Richmond, Niagara, and Mid-Devonian times—the sea covered the region (figure 4), but retired at the time of the Appalachian Revolution, when an overthrust fault took place (figures 6 and 7). Erosion reduced the land to a peneplain in Keweenawan time and exposes sometimes the block-fault, sometimes the thrust-fault.

History

The great Keweenaw fault, which bounds the south side of one of the greatest copper-producing regions, has been an important one not only eco-

[1] Introduced by A. P. Brigham.

nomically and structurally, but in the history of geology. It is not necessary to review the literature recently summarized in United States Geological Society Monograph 52 and my own report on the Keweenaw series. I may, however, recall the names of Jackson and Foster and Whitney, Agassiz, Pumpelly and Wadsworth, Hubbard, Van Hise and Leith among those who have written on it. Very recently an important paper on Limestone Mountain, by Case and W. I. Robinson,[1] has appeared which has a bearing on the subject, as does also the work of Thwaites in Wisconsin.[2] I have also occasion to refer to the recent work of Allen and Barrett.[3] I have left until the last *honoris causa* the Monographic Bulletin 23, by Irving and Chamberlin, issued just 30 years ago.[4] It would be strange if 30 years of such active progress in research as the past 30 had not produced more facts and fuller

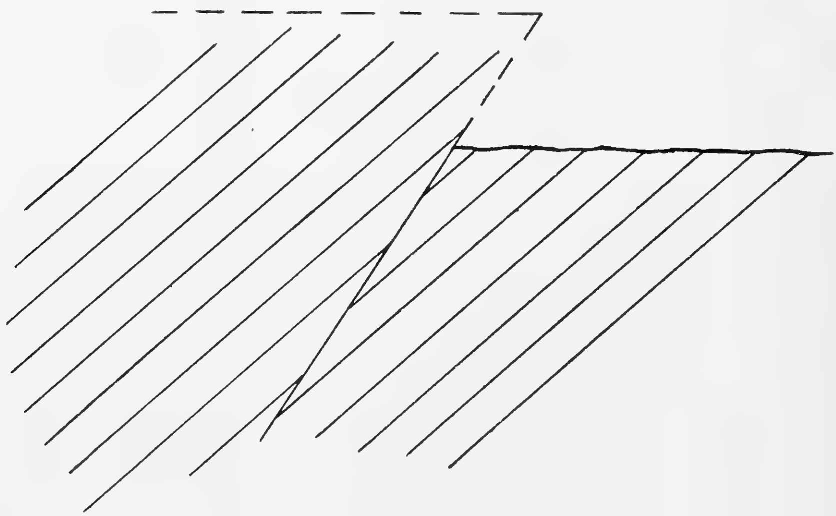

FIGURE 1.—*"Ideal Sketch of the primitive Keweenaw Fault"*
As represented in figure 24, page 113, of Bulletin 23, U. S. Geological Survey

light on the subject in a region which has been in the meantime the seat of much diamond-drilling and study.

In this paper I briefly compare three diagrams from Bulletin 23 with three others more nearly in accord with the facts as I now know them. Figures 1, 3, and 5 are figures 24, 25, and 26 of Bulletin 23, not pretending to be sections, but diagrams to explain the view of the authors. Figures 2, 4, and 6 are equally diagrams, not sections, for it would be impossible to get Limestone Mountain into a section with the Keweenaw fault on a sufficiently large scale. The bases are the corresponding figures of the set 1, 3, and 5 modified to

[1] Journal of Geology, vol. xxiii, 1915, p. 256.

[2] Sandstones of the Wisconsin coast of Lake Superior, Belt No. 25 of Wis. Geol. and N. H. Survey.

[3] Contributions to Precambrian geology. Mich. Geol. and Biol. Survey, Pub. 18, 1915.

[4] U. S. Geol. Survey Bull. 23. "Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior.

represent more nearly the geological structure. Figures 7 and 8 with 6 correspond to 5.

The Primitive Keweenaw Fault

We[5] agree that the faulting began in Keweenaw time. In figure 2, by changes from figure 1, I have tried to show (1) that *b* of the Keweenawan lies on the underlying Huronian unconformably, the beds in contact on the two sides

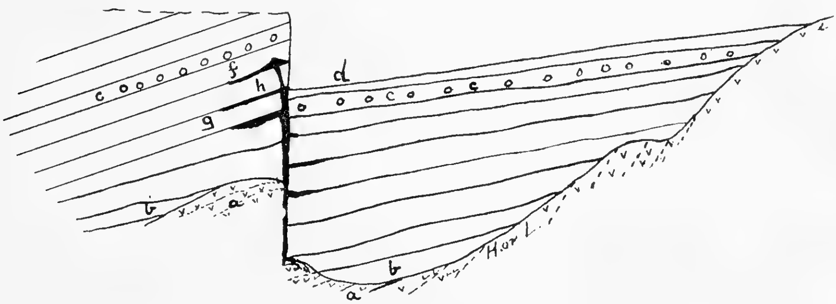

Figure 2.—*Ideal Sketch of the same Fault as Figure 1, supposing it to be a Block-fault*

differing many thousands of feet in horizon. This is well marked around Sunday Lake, as noticed by H. L. Smyth, Rose, and others. In fact, according to Allen's recent discoveries, the whole Upper Huronian was eroded away along much of the Gogebic range. (2) That this fault-line acted as a channel or conduit for volcanic activity, so that intrusive pipes (*h*) and sills (*g*) are

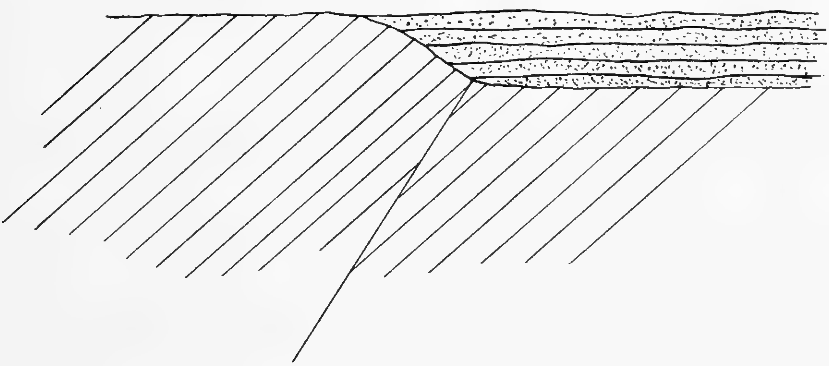

Figure 3.—"*Ideal Sketch of the Keweenaw Fault, after the Deposition of the Eastern Sandstone and before the secondary faulting*"

As represented in figure 25, loc. cit.

found near it—for example, Mount Bohemia gabbro, the Torch Lake quartz porphyry, Indiana Mine porphyries and gabbro, Berglund intrusives, etcetera—and the more viscous felsic lavas are also found near it. One period of eruption of rhyolites culminates before the deposition of conglomerate 8, (*c*) of

[5] "We" refers to the authors of Bulletin 23 and myself.

this figure. (3) Therefore I have changed the hade of the fault from that of an overthrust to the steep hade of a block-fault. There is some direct evidence of this. It is certainly not as flat as a later overthrust fault (Old Colony and Torch Lake and Oneco sections). A nearly vertical hade would be also a more natural channel for volcanic activities. Many overthrust faults are devoid of them.

Primitive Erosion

We agree, as shown in figures 3 and 4, that this primitive fault suffered erosion, and that the Eastern or Jacobsville sandstone may have lapped on both sides of it. But the study of land formations, which has much advanced in the last 20 years, would lead one to infer that the valley at *d* was being filled as it was formed, and that there is no such sharp gap in dip or strike or time of deposition between the Upper Keweenawan and the Cambrian sandstone, as is fairly inferable from figure 3. In fact, my own figure 4 does not do justice to my conception of the continuity of sedimentation that takes

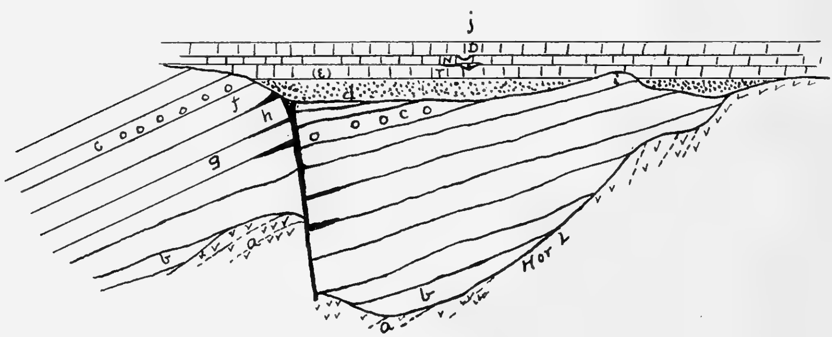

FIGURE 4.—*A Stage corresponding to Figure 3*

Showing the section after the deposition of the four Paleozoic overlaps

place in a block-fault valley or graben. The Keweenawan is for me largely the land facies (the Old Red Sandstone facies) of the Middle and Early Cambrian (Waucobic). We know now definitely through Thwaites and the Wisconsin Survey that the Upper Keweenawan is indistinguishable in lithology, dip, or strike from the Cambrian sandstones, for the "Western" Apostle Islands sandstones that have been hitherto called Cambrian by every one he classes as Upper Keweenawan, and the line between them and the Mississippi Valley fossiliferous Upper Cambrian sandstone is drawn in a region where there are no outcrops. However, Limestone Mountain at *j* has fortunately been left us (figure 8) to show that the "Eastern" sandstone is really directly beneath the Trenton. The Jacobsville or Eastern sandstone shows both in drill cores (as at the Oneco mine) and exposures fragments of the Keweenawan amygdaloids, that indicate clearly that at the deposition there was yet a little of the uplifted fault-block exposed to attack. The association of zeolites with copper shows the cooperation of thermal waters, and I therefore believe that much, if not all, of the copper deposition took place during this period of early erosion.

Relation of Keweenawan Formation to Cambrian and Precambrian

Before the deposition of the Keweenawan the Huronian was uplifted and suffered deep erosion, so deep that, according to Allen,[6] over a large part of the Gogebic Range the Neo-Huronian, which he calls the Copps formation, is removed. Consequently apparently Van Hise mistook the Animikie, or Middle Huronian, for the Upper Huronian. However great the pre-Keweenawan erosion may be, however, all agree that it existed. It seems to have gone so far and so nearly was a peneplain produced, in the later stages of which conglomerates must be finer and often absent, that coarse basement conglomerates of the Keweenawan are not often found. This is important, as indicating the importance of the gap separating the Keweenawan from the Huronian. The black shales of the Neo-Huronian also might indicate the fine-grained deposits of advanced baseleveling. The Keweenawan formation seems, however, to have been formed when the Huronian was raised above water in a desert something like our Great Basin. The dolomitic marls, the micaceous shales, the arkose sandstones, the slight chemical assorting or leaching of the sediments, as well as the abundance of salt, as I believe, largely connate waters, all favor this conclusion to which, I think, Leith came before myself. I have been especially interested lately in studying angular clay pebbles that I find in the Keweenawan drill cores, and take to be broken up, dried crusts on the top of desert clays. This desert basin formation, with accompanying lava flows, like those of the Snake River Valley of Oregon, lasted until late into the Cambrian; for the Upper Cambrian, Jacobsville, or Eastern sandstone, still is arkose, with as much as three-eighths of the sand grains feldspar, still micaceous, and still has saline, though not *so* saline waters. They become distinctly fresher in the upper part. These Upper Cambrian sandstones also contain pebbles of the Keweenawan, showing that the escarpment of the Keweenawan fault was neither peneplained nor covered at the time of the Upper Cambrian. So I think it is pardonable if I am more confirmed in the belief that the Keweenawan is more largely Cambrian than Precambrian—more parallel to the Triassic, with which it was once confused—than to the Permian. I emphasize the fact that the Keweenawan occurred after rather than before the great Precambrian peneplanation, because Lawrence Martin has acutely suggested this as a test whether the Keweenawan is really Cambrian. The line of contact of the base of the Keweenawan on the various Huronian formations is, as Allen's map shows, fairly smooth, except where disturbed by faulting that also affects the Keweenawan.

The Paleozoic Invasions

By the time the sea invaded the valley *d*, however, the fault-scarp was pretty well worn down, as figure 3 indicates, and though I have indicated the Eastern sandstone in figure 4 as not entirely covering the range, it may finally have done so, though even near Limestone Mountain (*j*) there are some small pebbles which may be Keweenawan. Such pebbles certainly come near the Keweenawan fault in strata which one would think are not much below. I

[6] Loc. cit., chapter iii, pp. 58-59.

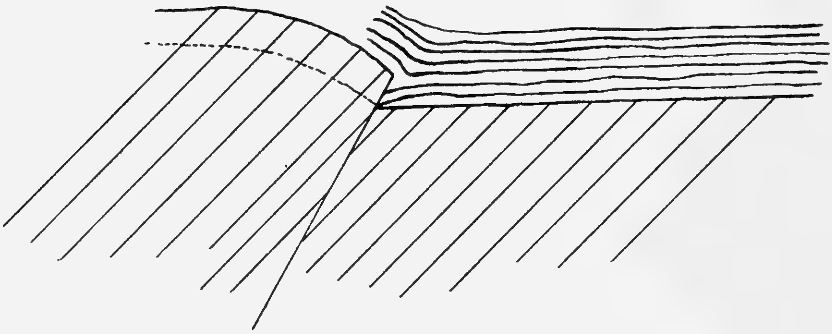

FIGURE 5.—*"Ideal Sketch of the Keweenaw Fault, after the secondary faulting"*
Loc. cit., figure 26, page 114

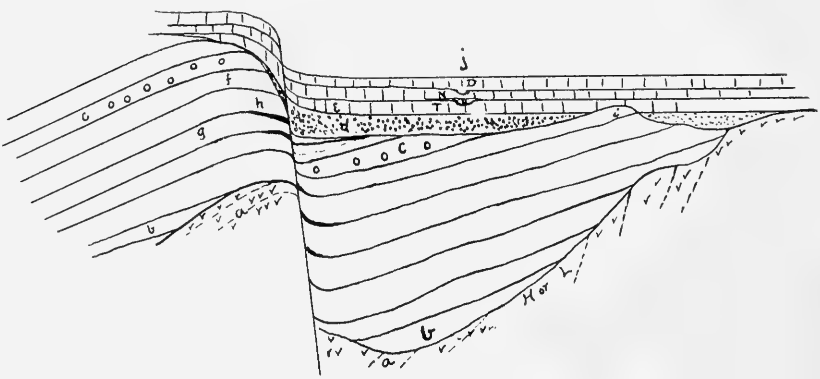

FIGURE 6.—*Ideal Sketch of the Keweenaw Fault just before the secondary Thrust faulting*

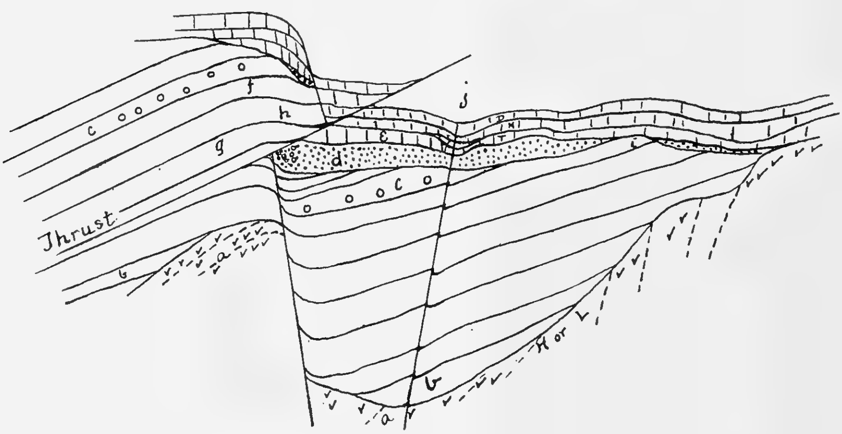

FIGURE 7.—*Ideal Sketch of the Keweenaw Fault just after the secondary Thrust*

wanted, however, to indicate the still greater expansion and greater distance from shoreline of the succeeding limestones.

During the Paleozoic we have no evidences of great disturbances; but four times, as Case and Robinson show, the sea advanced over the region, quite possibly when at periods of world-wide quiescence and peneplanation the oceans were so filled as to raise the sealevels at about the same time when, as four chief salients in Schuchert's curve indicate, there was wide-spread submergence of the North American continent. No unconformity and but little disconformity has yet been recognized in these strata in Michigan. They are indicated in figure 4 as practically conformable except near where Limestone Mountain was to be. I have indicated the Richmond as a mere filled channel in the Trenton, because it seems to have been less widely distributed in Michigan.

There may well have been, we should expect that there were, later Carboniferous invasions, all traces of which have been removed. There is little Devonian left.

We have then:

1. "Trenton"—Ordovician—Decorah—Black River.......................... T.
2. Cincinnatian .... R.
3. "Niagara"—Upper Silurian—Lockport .... N.
4. Mid-Devonian—probably Hamilton—compare the overlap at Milwaukee, Wisconsin .... D.

The first and third I had recognized years ago; the second and fourth Robinson has just recognized.

The Appalachian Revolution

Some time after the Mid-Devonian the faulting, folding, and disturbances of the "Eastern" sandstone took place, which on the whole are very slight, but which left us Limestone Mountain (*j*) as a fortunate remnant. I take it that the further disturbances along the Keweenaw fault, illustrated by figure 5, from Irving and Chamberlin, and 6 and 7, were at about the same time. They were certainly later than the deposition of the Eastern sandstone, and had there been much disturbance earlier than the Devonian I think it would have been registered at Limestone Mountain. Moreover, the earlier Paleozoic is generally quiescent in the Great Lakes region; but the Appalachian Revolution may well have had some effect even here. I have indicated this effect in two stages. In figure 6, I suppose, a continuation of the block-faulting. This is indicated by flatter dips, and even sometimes southerly dips, near the fault along the range (New Baltic and South Lake mines). Though such southerly dips may be produced by simple thrust, it is easier at least to draw them by supposing a monoclinic fold or faulting, such as shown, to precede the thrust. Moreover, the consolidation of the beds *b-d* with a greater thickness down to the Archean than on the side of *h* would naturally lead to some folding or slump faulting on that side. Either with or without this preliminary bending it is easy to see that the same tangential compression that has bowed Lake Superior and produced the thrust-faulting and folding described by Thwaites, striking on an uneven wall, with soft sandstone on one side and

hard trap on the other, would shear off the top and cause it to override the sandstone, as shown in figure 7. That the copper deposition was largely prior to this folding is shown by numerous facts. A copper-bearing lode is cut off by the underthrust Eastern sandstone. The Algomah mine, the Lake, and South Lake may be conceived of as working on one bedded lode folded so as to be exposed three times.

Later History

But all this time erosion was going on, and theoretically near this fault there must have been land deposits of Permo-Triassic age, some remnant of which may some day be found like the fragments of Cretaceous found in the Mesabi Range.

During Cretaceous time the peneplain must have been somewhat higher than the present surface. And sometime in the Tertiary, the down-cutting

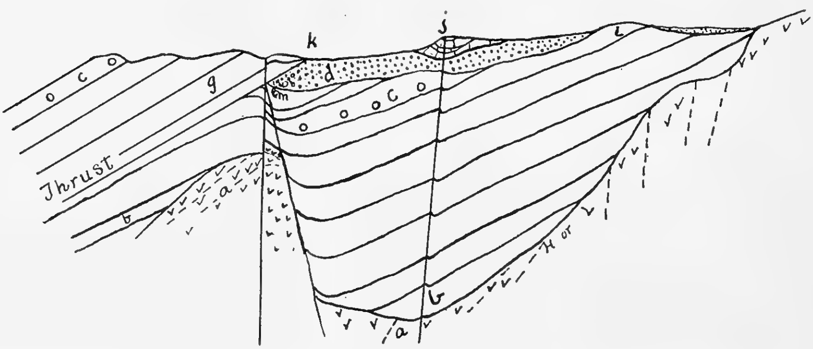

Figure 8.—*Ideal Sketch of a Cross-section through the southern Part of the Keweenaw (Copper) Range (ck), Limestone Mountain (j), Silver Mountain (i) to the Huron Mountains.*

streams reaching harder rock through the mantles of paleozoics, became more and more adjusted to the structure, though here and there transverse streams persisted in valleys now occupied by Portage Lake, the Flint Steel, Fire Steel, and Ontonagon. This Tertiary uplift presumably culminated in the Quaternary when this region was overridden by the Keewatin ice, and later was about the limit of the westward spread of the Labrador ice. At first the bedrock conditions are somewhat as in figure 8. Near the fault-line we find both thrust and vertical faults as well as slump faults, the strata disturbed and broken. The thrust-faults have a flatter hade than the strata and the thrust-faults a steeper. Both tend to cut out certain parts of the section.

The present surface level relative to the fault systems is sometimes higher, sometimes lower, so that in places we find the Keweenaw formation overlying the Eastern sandstone, as at *k* of figure 8, and again upturned against it, as would be the case did the present surface pass just above *m* of figure 8.

Presented in abstract extemporaneously.

SOME STRUCTURAL FEATURES IN THE GREEN MOUNTAIN BELT OF ROCKS

BY C. E. GORDON

(Abstract)

The Taconic, or, more broadly speaking, the Green Mountain belt of rocks, is notably, if not preeminently, a region of fracture. The great displacements are genetically of the reversed type, although in later adjustments there may have been some normal faulting along the planes of earlier reversed faults. These great fracture lines follow the general trend of the Green Mountain axis, but often cross it. An east-west trend of the foliations of the ancient gneisses, which has been observed at certain places, may be genetically associated with these transverse breaks if, as seems likely, the lines of weakness in these basal gneisses coincide with their structural features.

Erosion has been extensive enough to expose the faulted relations of the gneisses and the younger rocks. A reasonable restoration of the Precambrian floor on the basis of this faulting gives a different impression of the topography of the land over which the Cambrian sea transgressed from what the present topographic relations, viewed without recognition of the extensive fracture of the basal Precambrian floor, might convey.

Presented by title in the absence of the author.

FAULTING IN NORTH-CENTRAL KENTUCKY

BY ARTHUR M. MILLER

Faults which are all of the normal type, with prominent drag zones on their downthrow sides, are by no means uncommon in the Blue-grass region of the State, though, on account of the length of time which has elapsed since they were formed and the great thickness of residual soil covering, they are not always easy to detect in the uplands.

They vary in length from a few hundred yards to nearly 50 miles, and in throw from 5 or 10 to 350 feet.

They nearly always occur in pairs—a primary and a secondary fault—the latter evidently consequent on the former.

The adjustment of tension strains accompanying a bowing up of the Cincinnati Geanticline might well result in slippings along tension fissures. Such would constitute the "primary" faults. The dropping down with tilting in of the strata toward these faults would tend to develop parallel tension cracks at certain distances away from the primary cracks. A further slipping and tilting of the strata with the continued bowing up of the anticline would widen and deepen the developing secondary fissures until they, too, would become planes of slipping, constituting "secondary" faults, and the wedges of strata between the primary and secondary would become "fault-blocks."

This type of faulting is well illustrated in the West Hickman Creek fault strip, which stretches from near Paris, in Bourbon County, to near Union Mills, in Jessamine County, a distance of 25 miles.

The maximum throw near the middle of the strip of the west (primary) fault is about 150 feet. Nearly its whole extent is in the uplands of the Central Blue-grass region, where it displaces Eden shale on Lexington lime-

stone. It has formed with its secondary member a nearly continuous narrow strip of relatively poor Eden shale land, sharply contrasted with the excellent Lexington limestone typical blue-grass land on either side of it. This linear tract of beech-tree, sobby, "soapstone" land—from an eighth to a mile wide, penetrating the heart of the Blue-grass—the farmers of the region, in accordance with a tradition handed down from the early settlers, have been accustomed to account for on the theory that it is an "old buffalo trail." It passes 1 mile east of Lexington, and at this point was chosen as a site for the main city reservoir, the clay bottom it has furnished being excellent for holding water.

A very similar poor-land strip stretches from near Great Crossings, in Scott County, past Stamping Ground, in the same county, to near Peaks Mill in Franklin, a distance of about 12 miles.

The two bounding faults of this strip are the Kissinger (primary) and the Switzer (secondary). The amount of the throws and the strata displaced are the same as in the West Hickman, except that toward the western end Maysville (Upper Cincinnatian) has been preserved by being brought down on a level with the Eden.

The most prominent of these faults is that of the Kentucky River. It stretches from near Levee, in Montgomery, to near Burdetts Knob, in Garrard County, a distance of 50 miles. The maximum throw in the middle of the stretch is about 350 feet. It here displaces in the uplands Garrard sandstone and Lower Maysville on Lexington limestone, and at the bottom of the gorge of the Kentucky River Upper Lexington on Lower Highbridge (Camp Nelson). The general trend is north 70° east.

Another is the Glencairn fault, crossing the Lexington and Eastern Railroad at Glencairn Station. It stretches from near Campton, in Wolfe County, to near Irvine, in Estill County, a distance of about 25 miles. The maximum throw is about 150 feet. Through most of its extent it displaces at the surface Lower Pennsylvanian on Upper Mississippian.

The Kentucky River fault is so called because from Boonesboro, in Madison County, to Camp Nelson, in Jessamine County, a distance by the windings of the river of 41 miles, the general course of the river and the fault coincides. In this stretch the river in its meanderings crosses the fault nine times, flowing in a narrow picturesque gorge of hard Highbridge limestone, whenever it is on the northwest (relative upthrow) side of the fault, and in a wider valley, presenting less pronounced scenic features, when it is on the southeast (downthrow) side, where it is bedded in the softer limestones and shales of the Lexington or Eden.

While the general southwest diversion of the river in this course is in evident relation to the fault, the minor bends, or the meanders proper, bear no relation to it.

At the eastern ends the Kentucky River and Glencairn faults die out in monoclines which involve at the surface Mississippian and Pennsylvanian, and underneath strata at least as low as the Silurian, for it has resulted in the accumulation at these two ends of the Ragland and Campton oil pools respectively.

The Ragland was discovered accidentally as the result of wild-cat drilling, the Campton in response to advice given by the writer, based on what he

suspected was the relation in the former instance between the oil and the monoclinal structure and the monoclinal structure and the fault. Later a shallow oil pool was developed at the southwestern end of the Glencairn fault, near Irvine.

The oil horizon in the first two instances appears to be a magnesian limestone of approximately Clinton (Brassfield) age. In the Irvine wells the oil appears to come from the Columbus (Devonian) limestone.

In the Lexington limestone of the Blue-grass region are barite veins which have been rather extensively worked in recent years. They are in evident relation to the faults, being fillings of solution cavities, which are widened cracks usually extending outward from the faults at approximately right angles. The walls show no signs of any considerable vertical displacements, but there is some evidence of horizontal movements.

All this fissuring and faulting appears to be of the same age, which is post-Pennsylvanian, as Pennsylvanian strata are traversed and displaced by some of them.

It is also evidently pre-Tertiary. The latter conclusion is reached from a study of the relations of the Kentucky River to its fault.

The Kentucky appears to be a superimposed river which formerly crossed a baseleveled Cincinnati arch in a northwesterly direction from the present site of Boonesboro to where Elkhorn Creek now empties into it. This would carry it by the present site of Lexington.

As the river during a subsequent period of rejuvenation cut its way deeper into the strata, it came more and more under the influence of the fault, the effect of which was to cause it to veer in its course to the southwest.

The excellent illustrations of intrenched meanders in this portion of its course, as in other portions, would seem to indicate that the diversion was before any of the present meanders were acquired.

These meanders are supposed to date from a period of Tertiary baseleveling, hence the Kentucky River fault, and apparently all the other faulting as well, is pre-Tertiary.

We have independent evidence that the Cincinnati Geanticline was first formed in late Silurian or early Devonian time (researches of Foerste). It appears to have received a second bowing up after the aggradation period of the Pennsylvanian, which followed the complete peneplanation just before the latter period was ushered in.

Provisionally we may assign this faulting to the post-Pennsylvanian revolution.

Though now only the eastern end of the faults traverse and displace Pennsylvanian strata, there is strong evidence from outliers scattered out over the Blue-grass region that the strata from the Ordovician up to and inclusive of the Pennsylvanian—except very uppermost Silurian and lowermost Devonian—once went over the Cincinnati arch.

The recentness of the strata preserved in these faulted outliers is generally proportional to the amount of the throw in the faults and the distance they are situated from the axis of the arch.

One very instructive example is Burdetts Knob, near the southern end of the Kentucky River fault, almost on the summit of the central anticlinal dome.

Here is preserved a little patch of Lower Mississippian.

One can hardly avoid the conclusion that the Mississippian went over the arch; and if the Mississippian was thoroughly baseleveled before the deposition of the Pennsylvanian, it is hard to escape from the inference that the latter must also have stretched across.

Presented in abstract extemporaneously.

Discussion

Prof. Frank R. Van Horn: In Professor Miller's discussion of the faults, with mention of the barite veins, he omitted to state that the veins contain small amounts of galena and sphalerite. It is probable that the Lexington veins are similar in origin of those of southern Illinois and western Kentucky, in Caldwell and Crittenden counties, where the same mineral association was found, except that fluorite is the gangue mineral instead of barite. In this latter region the veins were worked at first for the lead, but lately for the fluorite, which was used as a flux.

MECHANICS OF INTRUSION OF THE BLACK HILLS PRECAMBRIAN GRANITE

BY SIDNEY PAIGE

(*Abstract*)

A consideration of the Black Hills granite intrusion may throw light on the mechanics of intrusion in general.

Field relations indicate that the Black Hills granite came into its present position in the main by physical distension of the invaded rock body, under great load. The schists were deformed by the advance of the magma; were forced into closely appressed recumbent folds. The schistosity produced by this folding lent itself to further injection by the granite through great numbers of parallel dikes and by intricate lit-par-lit intrusion. The harder rocks—the quartzites—were distended and broken apart by the upward movement and the magma flowed in between the blocks.

It is believed the magma was intruded at a relatively low temperature; that it contained considerable water, and acted as a relatively mobile mass.

The relation of dikes to schist layers, the fact that lit-par-lit injection tends to neutralize chemical and physical differences between magma and invaded rock, the probable low temperature of the granite, and the fact that positive evidence of much assimilation is lacking—all support the belief that this process was but a corollary of physical displacement, and not a primary process by which the forward movement of the magma was accomplished. The possibility that large blocks of roof have been engulfed in the magma, and that this process was an important one, must remain an open question.

Presented in abstract extemporaneously.

Discussion

Prof. Joseph Barrell: Mr. Paige has shown in his discussion of the field relations of the Black Hills granite that they indicate intrusion in the main, by physical distension of the invaded rock body, under great load.

This may seem at first sight to be an argument against the validity of other modes of intrusion in other regions, more especially against the validity of the stoping hypothesis. Although, as Daly has said, the stoping hypothesis was postulated independently by a number of geologists, it has been so largely developed by his work that he is deservedly regarded as its chief founder and expositor. As one of those, however, who have contributed papers in which it is held that the rise of certain batholiths was by stoping, it seems appropriate for me to speak of the relations of the two modes of intrusion. The invasion of the Black Hills granite by crustal distension seems a logical conclusion, but at the same time does not controvert the evidence that certain other bodies have risen to their final boundaries by a process of stoping. In this statement I am not taking exception to Mr. Paige's conclusions. In fact, we have discussed this topic and I think we agree; but where a more or less novel view, such as the stoping hypothesis was ten years ago, is advocated as an explanation of certain examples, the idea is apt to arise among readers that the expounders wish to give it a universality of application and eliminate competing hypotheses.

What, then, is the adjustment of factors which in one case may lead to lateral displacement as a chief mode of invasion, in another case to overhead stoping, permitting a passive rise? The rise of magmas from abyssal depths would appear to result from the unbalancing of a hydrostatic equilibrium. The liquid column is lighter than the surrounding rocks. As the liquid arises above that datum plane where the liquid and solid are under the same pressure, the internal pressure at any level is diminished by the weight of the column of liquid below; the pressure in the surrounding rocks is diminished by the greater weight of the rock column between the level and the datum plane below. A bursting and intruding pressure is consequently developed. In the zone of flowage the thick cover would permit this internal pressure to act laterally, pushing the walls aside. Injection into the roof in steep foliation planes also implies a lateral distension. More or less doming of the cover is of course also to be postulated.

When a large magmatic body has advanced, however, comparatively near to the surface, a lateral distension of the walls or cover becomes subordinate, because the line of least resistance is now for the magma to dome the cover upward, to produce intrusion fractures, and to intrude in distinct sheets and dikes, rather than to produce a *lit-par-lit* injection. The mechanical conditions making stoping a dominant process are then found especially in the zone of fracture; those making for injection, mashing, and crystallization with lateral distension of the wall rocks prevail in the zone of flow. The Black Hills granite belongs to the Precambrian. In these ancient batholiths crustal distension by the invading magmas appears to have been a dominant process, though stoping even here may have participated. The far younger batholiths of the Cordillera were intruded to high levels and with more or less absence of compressive forces. In these stoping appears to be a dominant process in the higher stages of their invasion. If we could restore the great depths eroded from the Archeozoic and look at the former higher levels, or if we could look deeper into the crust to observe the relations of post-Jurassic batholiths yet concealed, the distinction in dominant modes of intrusion evident between the older and younger periods of igneous activity might be found to have largely disappeared.

Mr. Charles E. Decker: Having heard that an unconformity had been found in the Precambrian in the Black Hills, I should like to ask Mr. Paige about the conglomerate he mentions in his paper. Is it a basal conglomerate, and is there evidence of an unconformity beneath it?

Brief remarks were made by Prof. R. A. Daly.

Mr. Paige replied: I am gratified that both Professor Daly and Professor Barrell agree that the Black Hills granite may have come to place in such a manner as I have indicated. The idea that the variation in the mechanics of igneous intrusion is a function of depth and temperature has long appealed to me as reasonable; that magmas and the rocks that they invade must act differently at varying depths seems a logical deduction from what we know of the earth's temperature and pressure gradient and from what we have observed in the field. The idea, carried to its ultimate analysis, demands that there should be a region at very great depths where, due to intricate injection and prolonged impregnation by the magma, sediments will break down and lose their identity as such, taking on all the characteristics of igneous rocks.

PRECAMBRIAN STRUCTURE OF THE BLACK HILLS, SOUTH DAKOTA

BY SIDNEY PAIGE

(*Abstract*)

A study of the Precambrian rocks of the Black Hills reveals a great series of slates and schists, for the most part monotonously alike, striking in a northwest direction, and having steep dips, generally, except in the extreme southwest, to the east. At the south intrusions of granite break through the strata, and around the principal mass of granite about Harney Peak a schistosity is developed parallel with the granite contact.

A closer study shows that the persistent eastward dips represent both schistosity and bedding, the two for the most part parallel, and that the series is compressed into a number of great folds which comprise innumerable minor isoclinal folds.

And, finally, a sufficient number of individual beds can be traced to locate the position and nature of the greater axes of folding and to detect the presence of two important faults.

The nature of the granite intrusion is such as to lead to the belief that the mass exerted an important influence on the folding, and the position of one of the faults was the determining factor in the localization of the great Homestake ore body.

Presented in abstract extemporaneously.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE AFTERNOON SESSION AND DISCUSSIONS THEREON

The Society convened at 2 o'clock p. m., with President Coleman in the chair.

The Society proceeded immediately to the consideration of scientific papers.

RECTILINEAR FEATURES IN THE EASTERN CATSKILLS

BY GEORGE H. CHADWICK

(*Abstract*)

It seems to have escaped notice that there is in the eastern Catskill Mountains a series of right-line valleys gridironed across the ranges in a direction 15° east of north similar in character to those features in the Adirondacks that have been interpreted as due to block-faulting; but no proof is at hand that such faults exist in the horizontal red beds of the Catskills. The valleys indicated are, however, parallel with the mural front of these mountains facing the Hudson Valley and with the strike ridges of folded Helderberg limestones in that valley, a few miles distant. The field evidence suggests that the cause of these features is a close spacing of joints along zones at intervals.

Presented in abstract extemporaneously.

Discussion

Mr. John L. Rich: Mr. Chadwick has presented a very interesting paper, and with his primary thesis I am heartily in accord. With regard to the straight mural front of the Catskills, which is interpreted as probably a product of glacial erosion, I wish to suggest the alternative hypothesis that, since it parallels the folding in the Hudson Valley to the east, it may be rather a structural feature representing the eastern limit of the flat-lying beds.

The speaker suggests that the roughly accordant, flat-topped summits of the higher Catskills may be remnants of a peneplain, possibly Jurassic. Without specifically opposing this proposition, I wish to give expression to my increasing distrust of the verity in regions of horizontal rocks, particularly where some beds are distinctly more resistant than others, of peneplains for which the only evidence are small flat areas on the summits and accordant altitudes.

Dr. W. J. Miller: In the eastern Adirondacks there are numerous normal faults, proved to be such by most of the familiar criteria for the recognition of faults. In many other cases, however, there are prominent zones of excessive jointing, often showing more or less evidence of faulting by the slickenside, fault breccia, etcetera. In other cases such evidence of actual displacement is lacking. Many times it is difficult to decide whether a given zone is due simply to excessive jointing or whether the jointing has accompanied actual faulting in the zone.

Doctor Chadwick replied to Mr. Rich as follows: The peneplains bevel across the rock layers, and consequently are independent of the harder layers except for short intervals.

Doctor Chadwick replied to Doctor Miller as follows: There is no question of the existence of faults in the eastern Adirondacks, but it is unsafe to assume that all similar rectilinear valleys are of fault origin, and particularly in the northwestern Adirondack region, where the work of Doctor Martin fails to find faults, although the physiographic features are similar.

PHYSIOGRAPHIC EVIDENCE OF RECENT SUBSIDENCE ON THE COAST OF MAINE

BY CHARLES A. DAVIS

(*Abstract*)

For several years the author has been collecting evidence which seemed to him to prove a recent subsidence of the North Atlantic coast, still in progress.

Some of these evidences have already been presented before this Society. During the summer of 1915 some attention has been given to the physiographic evidence of subsidence presented by certain beaches in southwestern Maine, where an ancient beach was found almost buried in a salt marsh, which clearly must have been formed subsequent to the beach. The unaltered crest of this old beach is several feet lower than that of the modern beach of exactly the same type. Other beaches with multiple ridges in the same region give noteworthy confirmation of the evidence furnished by the one mentioned.

Some other physiographic evidence of subsidence now in progress was presented, and this was shown to be fully in harmony with other types of evidence already presented in former papers.

Presented in abstract extemporaneously.

PHYSIOGRAPHIC NOTES ON THE WHITE MOUNTAINS

BY DOUGLAS W. JOHNSON

(*Abstract*)

The paper presents certain observations made during a brief visit to the White Mountains in the summer of 1914.

The origin of the felsenmeer or block moraine, the date of cirque formation, and the position of the New England peneplain with reference to the mountains are briefly treated.

Presented by title in the absence of the author.

POSITION OF THE NEW ENGLAND UPLAND IN THE WHITE MOUNTAINS

BY ARMIN K. LOBECK [1]

(*Abstract*)

An attempt to trace the New England peneplain from the base of Mount Monadnock to the White Mountains has led to the unqualified conclusion that in the latter region the peneplain lies near the base of the mountains, and that the mountains represent monadnocks rising far above the badly dissected upland surface. In addition to the field evidence, a study of the topographic sheets east of the mountains and Hitchcock's Atlas of New Hampshire, by means of projected sections, decisively supports the conclusion.

Presented in abstract extemporaneously.

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[1] Introduced by Douglas W. Johnson.

STUDY OF RIPPLE-MARKS

BY WALTER A. BUCHER [1]

(*Abstract*)

The mechanics of the problem; mathematical laws; results of new experiments; significance in stratigraphy; field observations in Kentucky and Ohio.

Presented by title in the absence of the author.

DEAD LAKE OF THE CHIPOLA RIVER, FLORIDA

BY E. H. SELLARDS

(*Abstract*)

The Chipola River in Florida affords a good illustration of a tributary stream ponded by the deposition of sediment in the valley of the main stream. This river, which originates entirely within the coastal plain, flows for a considerable part of its course across limestones and is fed very largely by clear water limestone springs. It is therefore a clear-water stream, carrying only a limited amount of sediment. The Apalachicola River, of which the Chipola is a tributary, heads on the contrary in the mountains of northern Georgia and receives a heavy load of sediment, which is deposited, as the river becomes overloaded, near the Gulf. The Chipola enters the Apalachicola about 25 miles, by land, from the Gulf of Mexico. In this lower part of its course the Apalachicola is rapidly aggrading its valley, while the Chipola, owing to the limited amount of sediment which it carries, is building its valley much more slowly. This condition results in flooding the valley of the Chipola River. The lake thus formed, known as the Dead Lake of the Chipola River, derives an added interest from the fact that it has come into existence so recently that the cypress timber of the former river swamp, now mostly dead, is still standing, although the water in the lake has reached a depth of from 10 to 20 feet, while the lake itself is 10 or 12 miles long and from 1 to 2 miles wide. The channel of the river may still be followed in its winding course through the lake.

Presented in abstract extemporaneously.

TECTONIC LINES IN THE HAWAIIAN ISLANDS

BY SIDNEY POWERS [2]

(*Abstract*)

The alignment of the Hawaiian Islands shows that they have been formed at the points of intersection of two sets of tectonic lines, one set running parallel to the group of islands from northwest to southeast, the other set being cross-fractures from northeast to southwest. On the island of Hawaii the rift lines of Mauna Loa and of Kilauea are quite pronounced structural

[1] Introduced by Nevin M. Fenneman.
[2] Introduced by John E. Wolff.

features following the second set. In the case of Mauna Loa, one rift starts near Hilo, on the east coast, and the other from Ka Lae, the southernmost point of the island, and at their intersection the sink of Mokuaweoweo has been formed. South of Mauna Loa are the almost parallel rifts of Kilauea: one from the east of Pahala, on the south shore; one from near the Olaa Mill, on the northeast, and a third from the line of pit-craters on the east—all intersecting in the sink of Kilauea.

Extensive faulting, not clearly related to the above tectonic lines, has accompanied the formation of the islands. On Niihau the eastern portion of the original volcano has dropped out of sight, leaving a line of sheer cliffs. Kauai was originally a volcanic doublet, but the volcanic pile on the northwest has subsided, as is seen in the truncated flows of the Napali cliffs. On Oahu a portion of the Kaala Range may have dropped down in blocks, forming the "pali" (cliff), and cinder cones with some lava flows may have risen between the crags, giving rise to part of the present topography. On the north side of Molokai there is a line of cliffs, rising to a height of 1,000 to 3,500 feet, which bounds the southern third of the original volcano. After the collapse of the northern two-thirds, lava flows built up a small peninsula at the foot of the cliffs, and on this peninsula the leper colony is now situated.

On Hawaii the breakdown of a portion of the Kahala dome is marked by cliffs on the northeast shore. The west side of Mauna Loa is scarred by a crescentic-shaped fault from Kealakekua southward, along which there has been subsidence on the seaward side. Later flows of lava have run over the cliffs and obscured the fault-line. The crater of Mohokea forms a crescentic depression on the south side of Mauna Loa, but the age of this crater, with respect to Mauna Loa, is uncertain. The south side of the dome of Kilauea, near the sea, from Kalapana nearly to Punaluu, has dropped down in a series of steps over which the later lava flows have poured from far back in geologic time until the last flow of 1868. The last movement along this shore was a subsidence of from 4 to 7 feet in 1868.

Presented by title in the absence of the author.

BANDED GLACIAL SLATES OF PERMOCARBONIFEROUS AGE, SHOWING POSSIBLE SEASONAL VARIATIONS IN DEPOSITION

BY ROBERT W. SAYLES [1]

(*Abstract*)

Above the Squantum tillite, which I described last year, there is a series of banded slates about 800 feet in thickness. The manner of transition from the tillite to the slate, with no unconformity, makes it certain that the slate was the result of deposition in waters from the melting of the glacier which formed the tillite. The first of the transition beds are conglomerates alternating with sandstones. Then come sandstones alternating with slates. Here and there it is plain that the ice readvanced over these beds, plowing them up and often dragging upward into the mass thus formed irregular lumps of the clay. Two beds of tillite in the slate itself show the close association of the slate with

[1] Introduced by J. B. Woodworth.

the main tillite. One of these beds is about 50 feet from the main tillite formation and the other about 150 feet. Prof. John E. Wolff has made a microscopical examination of the tillite and slate and finds that they have the same mineralogical composition. As one goes upward in the banded slate it is seen that the layers of sandstone become thinner and thinner, then disappear entirely, and finally the alternating layers are shown only in slate of dark and light bands, the dark bands containing more heavy basic material than the light. The cause of this disappearance of the sandstone layers can be explained by the gradual withdrawal of the glacier and the consequent slackening of the currents, which would be strong enough to carry sand only in the neighborhood of the ice. The lower pebbly members of the transition beds show irregularities of deposition, especially in lenticular forms, due to the inconstant conditions of streams coming from a glacier. A regularity of alternation in deposition, however, becomes evident after the first 50 feet or so of the transition beds have been passed, where the layers indicate deeper and quieter water, and thus more uniformity in deposition. The thin individual layers of sandstone and slate now show through hundreds of feet such regularity in thickness and interval that a regularly recurring cause must be sought.

Professors B. K. Emerson and Gerard De Geer have described this same regularity of layers of sand and clay in the glacial clays of the Connecticut Valley and Sweden respectively and have ascribed the banding to yearly deposition. They believe that the layers of coarser material indicate summer, when the streams from the melting ice were rapid, and the layers of fine material indicate winter, when the streams had less velocity. Neither Emerson nor De Geer could suggest any other period to which such regular alternations could be related. Other American geologists have published this same idea which De Geer conceived in 1878. Among them may be mentioned Dr. Charles P. Berkey, Prof. A. P. Coleman, and Mr. Frank B. Taylor. This explanation may not be generally accepted, but no other cause, so far suggested, accounts for all the facts of the case. When the seasonal units have been accurately determined, they will furnish a basis for estimating the length of time required for the deposition of the formation.

The facts observed in the slate at Squantum resemble so closely those described by De Geer and Emerson that it would seem as if there must be a very strong probability of these being similar cases, in spite of the millions of years which separate the two Glacial periods.

Read in full from manuscript.

Discussion

Prof. W. W. Atwood: This paper appeals to me as particularly interesting. I have seen similarly banded clays associated with the Wisconsin drift and during the past season I found just such banded clays associated with the Eocene till of southwestern Colorado. In examining in the field the slates here described by Mr. Sayles I was convinced that the regularity of the repetition of the bands of sands and clays meant a regularly returning cause, and seasonal changes in stream action seem adequate. This paper suggests that the idea of seasonal changes in deposition so well put forth by De Geer and others may help us in working out a calendar of ancient geologic time and

lead to a fuller appreciation of the significance of varying climatic conditions on sedimentation.

Professor Hobbs: I have been greatly interested in Mr. Sayles' able discussion of this subject and the conclusions which he has reached concerning the annual deposits indicated by the tillite. It was my good fortune to examine with Baron De Geer a number of sections in the thin-banded clay in the delta deposits along the former ice-front of Scandinavia. Checked as these individual bands were by moraines of annual deposition, and worked out as they have been with such infinite care, one could hardly fail to accept the conclusion to which they pointed. The conclusions of Mr. Sayles point the way for many studies in the future which it is certain will be crowned with results. I was interested to note that in some of his sections there was indication of what represents, perhaps, a climatic cycle, something entirely to be expected, though it did not seem to be indicated by the banded clays near Stockholm.

Prof. Joseph Barrell: Doctor Sayles has given a very convincing presentation, showing that the banding in the argillites associated with the Squantum tillite corresponds to the similar banding in Pleistocene glacial clays and is to be interpreted as showing seasonal variations in the Permocarboniferous glacial climates. This is both interesting and important, since the biologic evidence of most periods previous to the later Mesozoic shows warmth without marked zonal climates extending into high latitudes.

In the combinations of winter and summer conditions which go to make up the geologic climates, there are four combinations possible, so far as warmth and cold are concerned: *First*, winter may be submerged and summer is dominant throughout the year, with or without a season of drought. This is the present climate of the torrid zone and in a number of past times appears to have been the dominant type even into high latitudes. It means the existence of some condition which carried solar heat received in equatorial latitudes into high latitudes with minimum loss by radiation. *Second*, winter and summer may alternate, but with mild winters, the present climates of the warm temperate latitudes. This was perhaps the commonest type of climate in high latitudes during the Jurassic and Cretaceous periods. *Third*, winter and summer may alternate, but with rigorous winters, leading, with sufficient snowfall, to glacial conditions. This is the climate typical of high temperate latitudes today, but in the Pleistocene it extended into middle latitudes. It is favored by direct and local absorption of solar heat and its re-radiation, with minor control by a planetary distribution of equatorial warmth. It seems, as Doctor Sayles has here shown, to have been the type also of the Permocarboniferous glaciation in eastern Massachusetts. *Fourth*, the climate may be continuous winter, as seen *within* the present ice-sheets in polar latitudes—summer completely submerged, winter continually dominant.

Now, regarding the obliquity of the ecliptic and position of the pole as unchanged through geologic time, the middle latitudes should show the greatest contrast between the total amounts of winter and summer insolation. Doctor Sayles' paper suggests, in accordance with this expectation, that glaciation in all times in the temperate zone has been connected, as at present, with a marked seasonal climate, exhibiting the third of the several combinations listed—a climate distinguished from normal geological climates by the emergence of winter.

Let us go much farther back in time. A similar stratigraphic banding exists in argillites associated with the Huronian tillites at Cobalt, Ontario. I was fortunate in being able to examine this section under the guidance of Messrs. Miller, Knight, and Coleman during the International Geological Excursion in 1913, although they are not responsible for the following statement of observations.

The banding has, I believe, been noted for a long time by the Ontario geologists and may have been discussed in their reports. At the south end of Cobalt Lake occurs a thick bed of argillite delicately banded, indicating rhythmic deposition. The bands are grouped in series which show larger rhythms. If the bands are annual, the rhythmically recurring groups show climatic fluctuations covering periods of years. On the southeast side of Cobalt Lake the argillites are succeeded by a ripple-marked quartzite. The thick till sheet rests on this without obliterating the ripples or crumpling the argillite beds at a greater depth. The boulder conglomerate is faintly bedded with grits and some beds of banded argillite show occasional subangular boulders dropped into them. Many of the boulders are markedly soled and indicate undoubted glacial wear. The whole suggests the presence of quiet water, which at first was far enough from the glacier front to receive only silt and clay. Later it was mantled apparently by an iceberg deposit rather than a true ground till. This implies, however, true till in some region not far distant. At a later stage there may have been an overriding of ice in this same region. In other places at Cobalt what appears to be undoubted tillite containing striated boulders rests directly on the floor of Keewatin rocks, although the final proof, consisting of striations on that floor, has not yet been found. The association of these banded argillites with iceberg deposits and ground moraine indicates, therefore, the existence of summer melting and winter freezing during the Huronian glaciation.

Sederholm also has found in Finland as far back as during Bottnian time a regular alternation of clayey and sandy material which he interprets as an annual stratification, explainable only by assuming a regular change of seasons.

Glacial conditions then seem to be brought about by a marked lowering of the mean annual temperature of the whole globe, accompanied by an accentuation of seasons in middle latitudes. This suggests a less effective spreading out of equatorial warmth at such times and a more direct and rapid absorption and also radiation of solar energy in the temperate zones. Glacial periods are marked by strong seasonal climates, the emergence of winter. This is a fact which, according to its distinctness, must enter into the adjustment of factors bearing on the causes of Glacial periods. The explanation of non-glacial climates must, on the other hand, account for the submergence of winter in middle and high latitudes with the earth's axis permanently situated as it is at present. The explanation of glacial periods and of warm-pole periods are equally important and complementary problems. The presence of marked seasonal climates in temperate latitudes during glacial periods is an important fact which must enter into that explanation.

Mr. Frank B. Taylor: Laminated pebbleless clays formed in the preglacial lakes which followed the retreating Wisconsin ice-sheet occur in many places in the Great Lakes region. A deposit of this kind occurs at Bracebridge, in

the highlands east of Georgian Bay. It is nearly 100 feet thick, and if the successive pairs of laminæ be regarded as marking annual periods of deposition, this deposit, as I now recall it, would indicate a time of about 2,500 years for its formation. It has seemed to me that laminated clays of this type are particularly characteristic of deposition in association with the retreating ice-sheet, and it is a striking and impressive fact to find precisely similar clays greatly indurated and so closely associated with the ancient tillites.

Mr. John L. Rich: In a bottom of an old pond I once found a deposit of beautifully developed banded clays, in which the bands were marked by fragments of leaves. In this case the banding clearly represented seasonal accumulation, the leaf-bearing partings corresponding to autumn and winter, when the fallen leaves were being carried and deposited by the streams.

Prof. R. B. Woodworth said that Mr. Sayles' correlation of the banded shales with the tillite beds at Squantum added another group of water-laid deposits which have been identified among the ancient glacial formations wherein we should expect to find the equivalents of our Pleistocene and modern sand plains, kames and espars, and brick clays; already possible examples of one or another of these have been reported in Brazil and elsewhere.

GEOLOGY OF THE LAKE IDITAROD REGION, ALASKA

BY PHILIP S. SMITH

(*Abstract*)

The paper describes the areal geology of the Lake Clark-Iditarod region, Alaska. This region is located in southwestern Alaska, extending from the Pacific Mountains to the central part of the Yukon Plateau province. The rocks are dominantly sedimentary strata of Mesozoic age, but some Paleozoic limestones are also exposed. Igneous rocks, both of intrusive and of effusive origin, occur at a number of places, and certain of them seem to have been closely associated with the deposits of commercial value, such as gold and quicksilver. Unconsolidated deposits are widespread and throughout much of the region mantle over and hide underlying bedrock. These deposits are mainly of glacial and glaciofluviatile origin, though lacustrine, fluviatile, and volcanic ash deposits are also described.

Presented by title in the absence of the author.

CHARACTERISTICS OF THE SOIL AND ITS RELATION TO GEOLOGY

BY C. F. MARBUT

(*Abstract*)

The soil is made up mainly of rock-waste. Its characteristics are of two kinds: (1) those derived from the rock from which it came, or those that are inherited, and (2) those impressed on it by the forces that have been acting on it since its life history began, or those that are acquired. The latter characteristics are relatively few in number and vary with many factors. The conditions determining their character and strength of expression were discussed.

The relation of geology to soil was brought out by (1) a comparison of the chemical composition of a number of soils developed from the same rocks under varying conditions; (2) a comparison of the physical characteristics of a number of soils developed from the same rocks under varying conditions; (3) a comparison of the physical characteristics of a number of soils developed from different rocks under similar conditions; (4) a comparison of the physical characteristics of a number of soils developed from the same rocks under varying topographic conditions.

Presented in abstract extemporaneously.

GEOLOGIC SIGNIFICANCE AND GENETIC CLASSIFICATION OF ARKOSE DEPOSITS

BY DONALD C. BARTON [1]

(*Abstract*)

Different opinions are held as to the conditions under which arkose has been formed. A study of arkose deposits shows that they are of several distinct types, of which the more important are (*a*) deposits of great thickness and with fresh feldspars, (*b*) deposits of moderate size associated with coal and argillaceous beds, and (*c*) deposits of moderate size, more or less argillaceous and associated with red beds. A survey of the conditions under which arkose could be expected to form shows that the granular disintegration of granite is widespread and is a possibility under practically all climates; that in rigorous climates erosion and deposition of the granitic sand can take place contemporaneously with the disintegration, but that in regions of moist climate the mantle of vegetation must be critically weakened by some change of conditions, such as a marine transgression or increasing aridity, before the products of disintegration and decomposition beneath can be eroded and then accumulated. It therefore seems possible to formulate a genetic classification of arkose deposits.

Presented by title in the absence of the author.

SOME FEATURES OF THE KANSAN DRIFT IN SOUTHERN IOWA

BY GEORGE F. KAY

(*Abstract*)

In county reports issued by the Iowa Geological Survey and in other publications many of the features of the Kansan drift of southern Iowa have been described, including the original Kansan drift plain, the present topography of the Kansan drift, the tabular divides, the characteristics of the weathered and unweathered zones of the Kansan drift, the gumbo, which is closely related to the Kansan drift, and the fine, loesslike clay overlying the Kansan drift surface, and which has been interpreted by several investigators to be material of eolian origin deposited after a mature topography had been developed on the Kansan drift. The origin of the gumbo has been interpreted

[1] Introduced by R. A. Daly.

differently by different authors, the most recently published view being that of Tilton, who considers the material to have been formed, in the main, during the retreating stages of the Kansan ice. To this gumbo and other materials which he considers to be related in age to the gumbo he has given the name Dallas deposits.

Detailed field studies which are still in progress in southern Iowa seem to warrant the author in making a preliminary statement involving some interpretations which differ from those previously advanced.

(1) The surface of the Kansan drift, after the Kansan ice withdrew, was, according to present evidence, a ground moraine plain, which, from the main divide between the Mississippi and Missouri rivers, sloped gently to the southeast and south toward the Mississippi and to the southwestward toward the Missouri. This drift plain was so situated topographically that weathering agents were very effective, but erosion was slight. As a result of the weathering during an exceedingly long time a grayish, tenacious, thoroughly leached, and non-laminated joint clay, which has been named gumbo, was developed to a maximum thickness of more than 20 feet. This gumbo contains only a few pebbles, which are almost wholly siliceous, and grades downward into yellowish and chocolate-colored Kansan drift from 3 to 7 feet in thickness, in many places with numerous pebbles, few, if any, of which are calcareous. This oxidized but non-calcareous drift, in turn, merges into unleached drift, oxidized yellowish for several feet, below which is the normal unleached and unoxidized dark-grayish to bluish-black Kansan drift. The gumbo is believed, therefore, to be essentially the result of the thorough chemical weathering of the Kansan drift; but, subordinately, other factors, such as the wind, freezing and thawing, burrowing of animals, slope wash, etcetera, have undoubtedly contributed to its formation. The Kansan drift which has been changed to gumbo may have differed somewhat from the normal Kansan drift that lies below the gumbo.

(2) After the gumbo plain had been developed by weathering processes on the Kansan drift plain, diastrophic movements seem to have occurred, the plain having been elevated to such an extent that erosion became effective and valleys began to be cut into the gumbo plain. Erosion of the gumbo plain progressed to such an extent that some valleys were cut to a depth of more than 150 feet before grade was reached and a mature topography was developed. Only remnants of the original gumbo plain remain, the most conspicuous of these being flat, poorly drained areas, known as tabular divides. Where creep and slumping have occurred the gumbo, in places, may be found on slopes at an elevation several feet below the level of the gumbo plain. The tabular divides are more prevalent east of a line drawn north and south through south-central Iowa than west of such a line. In the southwestern part of the State the Kansan gumbo, which is *in situ*, is found only where the divides, which are no longer distinctly tabular, retain the level of the former gumbo plain.

(3) While there is, in places, loess of eolian origin on the Kansan drift of southern Iowa, much of the material which has been described as loess is thought to be not of eolian origin, but to be related more or less closely to the gumbo. The upper few feet of the Kansan gumbo, which is now limited to the tabular divides and divides closely related to tabular divides, is a fine-grained, loesslike, joint clay, in which, if diligent search is made, it is possible

to find a few very small siliceous pebbles similar to those in the normal gumbo, and it is thought that this loesslike clay is the result of changes that have been going on at and near the surface of the gumbo during the great length of time since the normal gumbo was formed. The loesslike clay which is now found as a mantle on the Kansan drift on the slopes and divides that have been brought by erosion considerably below the level of the original gumbo plain is believed to be the product not primarily of wind action, although wind may have been a factor, but chiefly the product of the weathering and concentration of the gumbo and to some extent of the underlying Kansan drift, where erosion has not kept pace with the weathering.

(4) The evidence indicates that the time taken to develop the present topography from the gumbo plain stage, although it represents a great length of time, is short when compared with the time taken to develop the gumbo plain from the Kansan drift. It is thought that the formation of the main part of the gumbo and the development of the present mature topography of the Kansan drift were effected between the close of the Kansan epoch and the advance of the Illinoian ice into Iowa; in other words, during the Yarmouth inter-Glacial epoch. All the evidence indicates that the Yarmouth epoch was an exceedingly long interval of time.

(5) Detailed chemical analyses of gumbo, loesslike clay, etcetera, are now being made in the chemical laboratory of the University of Iowa by Dr. J. N. Pearce. The results of these analyses will go far to strengthen or weaken the interpretations given above from the field evidence.

Presented in abstract extemporaneously.

Discussion

Mr. W. C. Alden: I would like to make a few remarks on the *Iowan drift* in connection with Doctor Kay's paper. I have seen a number of exposures of this clay on top of the Kansan drift, which, for want of a better name, we have called "gumbo." It seems to me a very important deposit. When first seen I thought it must be distinct from the underlying till, inasmuch as the till below it is oxidized, though the gumbo itself is mostly gray and unoxidized, excepting at the top. On further examination, however, I do not feel sure of its being distinct, and considerable evidence has been found indicating that it really may be the weathered upper part of the Kansan till which has been thoroughly leached of its soluble material and deoxidized. It is nowhere laminated like a water-laid silt, where I have seen it. It generally contains pebbles scattered sparsely throughout. The pebbles are mostly small and of chert and quartz, with some quartzites and crystallines, the latter badly decomposed. Rarely included boulders are found disintegrating and with feldspars decomposing to kaolin. Thicknesses of 15 to 20 feet of this clay are not uncommon. There is no definite line at the base of the gumbo; it grades into the till below. I am not yet fully convinced that it is the residuum of weathering of the upper part of the till, but there is much to suggest that this is the case. Probably Doctor Kay's investigations will settle the matter. If it is such, I think it indicates a very long time of exposure of the Kansan drift, prior to the Illinoian stage of glaciation, since the gumbo is also found under Illinoian till in Henry County, Illinois. It seems to make the Yarmouth in-

terval much longer than some of us have been inclined to think heretofore, especially since the development of the gumbo appears to have taken place largely, if not wholly, before the dissection of the Kansan drift plain. It seems to be confined to the flat uplands and does not mantle the eroded slopes. In any case it clearly marks a stratigraphic horizon, the top of the Kansan till.

The point to which I wish particularly to call attention is the relation of this super-Kansan gumbo to the *Iowan drift.* For a number of years past there has been considerable question in the minds of some of the geologists as to whether there really is a post-Kansan drift in northeastern Iowa. This was because of difference of interpretation of some of the phenomena. It was finally decided that the Federal Survey should cooperate with the Iowa Geological Survey in a critical review of the evidence in the field. I was assigned to this work with Morris M. Leighton of the Iowa Survey as assistant, and we spent the field seasons of 1914 and 1915 in the investigation. It is a pleasure to be able to announce that we have reached the conclusion that there really is good evidence of the presence of a post-Kansan drift sheet in that area; so that we are in the main in agreement with the late Doctor Calvin in regard to the Iowan drift.

We found the area much less markedly eroded than the Kansan drift area. The topography is of a peculiar type. We have called it a mantled, mature-erosion topography—that is, there are there the large patterns of maturely developed dendritic drainage systems—but most of the minor details have apparently been smoothed out. It is what one would expect if an ice-sheet were to spread over the maturely dissected topography of the Kansan drift area, wearing away the spurs, smoothing out the irregularities, partly filling the valleys, and mantling the whole with a rather thin sheet of till. This is indeed just what seems to have occurred. The slopes are very largely long, low, smooth, and, excepting close to the main streams, almost wholly uncut by lateral drainage lines. The minor valleys are shallow, open swales with smoothly rounded bottoms, where the streams flow in shallow trenches. There is a notable absence of the V-shaped cross-profiles seen in the Kansan area.

The uppermost drift throughout the Iowan drift area is a highly calcareous till. It is more modified by weathering than the Wisconsin, more so indeed than one would infer from some of the published descriptions, yet not nearly so much changed as the Kansan drift; neither is it so much modified as the Illinoian drift. The famous big granite boulders, although not entirely confined to the Iowan drift area, are notably abundant there and seem to be particularly characteristic of this drift deposit.

Now, the particular interest in regard to the super-Kansan gumbo is that it affords a new line of evidence which tends to corroborate the other data. Many new exposures have recently been afforded by grading for country roads, electric interurban railroad lines, and the Chicago, Milwaukee and Saint Paul Railroad; also we made about 250 test borings with an auger 8 feet in length. We have found numerous exposures of the super-Kansan gumbo, or a deposit exactly like it, in the higher parts of the Iowan area, those parts particularly where remnants of the original Kansan drift plain are likely to have been preserved. In several places there is a black carbonaceous bed at the top, apparently an old soil, and overlying this a thin deposit of later till—the Iowan till. Where this till is less than 4 or 5 feet thick, its limestone pebbles and

finer calcareous material have generally been entirely removed by leaching; where the drift is thicker than 4 or 5 feet, it is highly calcareous below the leached zone. At one place the gumbo bed outcropped in a slope about 50 feet below the top of the ridge.

It thus appears that there is clearly a post-Kansan till in northeastern Iowa. It is older than the Wisconsin and seems to be distinctly younger than the Illinoian. The loess, which is largely absent or very thin in the Iowan area, mantles the weathered and eroded surface of the Illinoian drift as it does that of the Kansan. A similar gumbo bed was found in western Iowa between two drift sheets, apparently the Kansan and Nebraskan, but this need not be discussed at this time.

Mr. Frank Leverett stated that in case the gumbo is a derivative from boulder clay microscopical examination should bring to light insoluble minerals, aside from siliceous rocks, that were combined to make up the rocks which are common in the boulder clay, but have not been found preserved in coarse fragments in the gumbo. The interpretation by Professor Kay seems at best but tentative and will need to be tested by such lines of evidence as are now under investigation, so that a year hence we may know better the value of the interpretation. So far as Mr. Leverett's personal observations have gone, there seems lacking the transition zone between boulder clay and gumbo which one would expect to find if the gumbo is a derivative from boulder clay. Usually less than a foot space will take one from typical boulder clay into typical gumbo, and one's first impression is that the gumbo has been deposited on the boulder clay as a distinct bed.

Mr. Charles E. Decker: I have seen examples of the gumbo which Professor Kay describes at the Survey Office in Washington. These samples are very much like a thoroughly leached clay that occurs in connection with the oldest drift in northwestern Pennsylvania at Franklin and Oil City. However, there are larger fragments of rock in the clay at those localities than in the specimens of gumbo.

TRIASSIC ROCKS OF ALASKA

BY GEORGE C. MARTIN

(*Abstract*)

Triassic rocks, including over 5,000 feet of limestones and shales with highly characteristic marine Upper Triassic (Karnic and Noric) faunas, are now known to be widely distributed in Alaska. The Middle and Lower Triassic are represented by a single known occurrence of marine Middle Triassic shales and possibly also by volcanic and metamorphic beds. The more important Alaskan Triassic sections were described and correlated. Correlations were also suggested with the Triassic occurrences in British Columbia, as well as with the better known Triassic sections in California and other parts of the world. An outline was given of the events of Triassic time in the northwestern part of America.

Presented in abstract extemporaneously.

LITHOGENESIS AND STRATIGRAPHY OF THE RED BEDS OF SOUTHEASTERN WYOMING

BY S. H. KNIGHT[1]

(*Abstract*)

The principal object of this paper is to announce the results thus far obtained from a detailed study of the red beds of southern Wyoming. This study is an attempt to determine, first, the origin and source of the sediments of which the red beds are composed; second, the physical conditions which were active during their deposition; and, lastly, their relations to contemporaneous and adjacent formations. The sections thus far studied in detail are exposed along the eastern flank of the Medicine Bow Mountains and along the western flank of the Laramie Mountains. This region affords a good opportunity for a study of this nature, inasmuch as there is a striking change in the lithological character of the lower half of red-bed series, as first brought out by my father, W. C. Knight, and later emphasized by Darton.

The change in lithological character throws considerable light on the direction from which the material was derived and the distance which it has been transported. Along the eastern flank of the Medicine Bow Range the lower half of the red-bed series (Casper formation) consists of about equal amounts of conglomeratic arkose and sandstones, with a very minor development of shale, while the same formation 20 miles to the east, along the western flank of the Laramie Range, exhibits in one section, which may be taken as typical, the following: arkose, 2 per cent; sandstone, 61 per cent; shale, 22 per cent, and limestone, 15 per cent. The total thicknesses of the formations in the two localities are 710 feet and 687 feet respectively. Owing to the size, angularity, and freshness of the feldspars in the conglomeratic arkoses, one may say that the material has not been derived from any great distance; this, together with the fact that these arkoses are practically wanting in the Laramie Range section, leads one to believe that the material had its origin to the west, probably from the region now occupied, in part at least, by the Medicine Bow Mountains. The evidence for the upper half of the series is not so clear, but it is hoped that some petrographical and mechanical analyses now being conducted will throw some new light on the problem.

We may now turn to the physical conditions which influenced the deposition of the red beds in this region. The evidence points to a continental origin for a large part of the series. Torrential, fluvatile, and eolian deposits have been recognized. The evidence for a continental interpretation may be summed up as follows: (1) Lack of continuity in sections measured at short intervals; (2) channeling to a depth of 10 or more feet; in one section seven erosion intervals were noted within 450 feet of the base of the section; (3) the ever-prevailing cross-bedding of both the torrential and eolian type; (4) the character of the material; (5) color; (6) lack of marine fossils. In this connection I wish to call attention to a striking conglomerate 150 feet from the base of the series, in an exposure on Sand Creek, Albany County, Wyoming. This conglomerate has a thickness of 34 feet and consists for the most part of water-worn pebbles and boulders of an igneous rock nature, the maximum

[1] Introduced by A. W. Grabau.

diameter of the larger boulders measuring 10 inches. Embedded near the base of this conglomerate were found a series of sandstone blocks, the largest of which measured 3 feet 8 inches by 7 feet 6 inches in its longest and shortest diameters. Thirty of these blocks were counted in 200 feet of outcrop. The material of which these blocks are composed consists of a fine-grained, evenly bedded, friable, red sandstone. These blocks are very angular in outline and the bedding planes of the various blocks are tipped at all angles. They present a strong contrast to the well rounded, smooth, hard pebbles and boulders with which they are embedded. It is evident from the size and angular outline, together with the friable nature of the sandstone, that these blocks have not been carried laterally any great distance, unless they can be conceived to have been floated or rafted by ice action. A careful search was made for some evidence of ice activities in the conglomerate, but none was found. In seeking for an interpretation which will account for the presence of these blocks in such a position, we have only to turn to some interesting facts recorded higher in the same section. It might be well to note that the lower 500 feet of the section, in which these blocks occur, is composed of heavy beds of a coarse sandy to conglomeratic arkose, interbedded with a number of thinner bands of fine-grained red sandstone, the materials of which are indistinguishable from those comprising the above-mentioned blocks. At a height of 330 feet from the base of the section one of these sandstone members was found to have a uniform thickness of 7 feet. Some 18 feet above this member (348 feet from the base) a second sandstone member, having a maximum thickness of 10 feet, was found to be channeled to a depth of 5 feet. At a distance of 370 feet from the base two large sandstone blocks, having regular bases on the same horizontal plane, were found to be completely inclosed by coarse arkose. The largest of these two blocks measured 26 feet long and 4 feet thick. Lastly, at a height of 416 feet from the base four sandstone blocks, all with regular bases in the same horizontal plane, were found completely inclosed by coarse arkose. The largest of this set measured 2 feet 6 inches in thickness, while the distance between the extreme ends of the two outer blocks was 50 feet. In all cases these sandstone members were found to have irregular upper surfaces, while their lower were approximately straight, and in each set on the same horizontal plane. From the foregoing it is apparent that we are dealing in each case with what was originally a continuous sandstone member, which, with the exception of the case noted at a height of 330 feet, has been channeled previous to the deposition of the overlying arkose members. In the cases noted from 370 and 416 feet from the base this channeling has cut completely through the beds, thus permitting the overlying and underlying arkose members to come together. We may carry this development a step further and assume that during a period of exceptional torrential activity, when coarse conglomerates were being deposited, such sandstone remnants of preexisting beds may have been undermined by the lateral cutting of a stream and tumbled into the river bed, where they would be deposited along with the pebbles and boulders being swept down by the torrent. This occurrence will be described more fully in a subsequent paper.

As to the stratigraphical relationships and age of this red-bed series, two points brought out by this research might be mentioned. First, that all of the limestone members (some ten having been recognized), which tend to repla[illegible]e

the red beds to the east, have yielded marine fossils. These fossils are now being studied in the Paleontological Laboratories at Columbia University. This fauna substantiates the previously recognized Pennsylvanic age of these limestones. In the Red Mountain region, near the Wyoming-Colorado boundary line, a thin red conglomerate was noted 177 feet below the base of the overlying Morrison shale. This conglomerate contains numerous bone fragments, mostly of a water-worn nature; but after a two-day search the writer was rewarded by the finding of a complete limb bone, the nature of which is yet undetermined. It is anticipated that this horizon, which was recognized in two sections 30 miles apart, will yield better material when thoroughly examined.

Presented by title in the absence of the author.

EXPERIMENT IN THE GRAPHIC PRESENTATION OF THE ECONOMIC GEOLOGY OF BEDDED DEPOSITS

BY GEORGE H. ASHLEY

(*Abstract*)

An attempt to present, by means of charts and maps, all of the known data concerning the resources of an area, so that, without the text, which in the main is confined to an explanation of the charts and maps, the reader may determine for himself the position on or under the surface, probable thickness, etcetera, of any and all beds of coal, clay, limestone, iron, etcetera, at any point in the area, so far as the data on hand warrant any conclusions.

Presented in abstract extemporaneously.

BRECCIATION EFFECTS IN THE SAINT LOUIS LIMESTONE

BY FRANCIS M. VAN TUYL [1]

(*Abstract*)

The Saint Louis limestone, as developed in southeastern Iowa and adjacent parts of Illinois and Missouri, is frequently so badly brecciated and disturbed that all semblance of the original structure is lost. The character and cause of this disturbance has until the present never been fully investigated, although it has been commented on by nearly all geologists who have examined the formation even casually.

Recent study of the Saint Louis has made necessary considerable revision of the formation as defined in previous reports. It is now known that the arenaceo-magnesian limestone sometimes shown at its base and formerly included with it is a distinct formation of the horizon of the Spergen limestone. This has been shown to be both physically and faunally distinct and to be separated from the true Saint Louis by a disconformity.

Moreover, the Pella member, which was formerly regarded as the topmost subdivision of the Saint Louis, is also formationally distinct. This bears a good Sainte Genevieve fauna and is separated from the true Saint Louis be-

[1] Introduced by T. E. Savage.

neath by a disconformity of considerable magnitude. It possesses a characteristic basal sandstone. As at present restricted, therefore, the Saint Louis represents only about one-half of the strata originally referred to it, or about 50 to 60 feet of limestone.

In southeastern Iowa the formation, as revised, is divisible into two well marked portions, which in their typical development are of about equal thickness. These are everywhere separated from each other by a slight disconformity. The lowermost of these is usually dolomitic, either wholly or in part, and the lower portion of the upper one is sometimes so. To the northwestward the upper division soon disappears, but the lower one continues to the north-central part of the State, overlapping older and older formations, until at Humboldt it is found resting on beds of Kinderhook age.

Where undolomitized, both divisions of the Saint Louis consist typically of fine-grained, compact, brittle, gray limestone, which breaks with a subconchoidal fracture. Beds of granular limestones a few feet in thickness, however, appear at some horizons, and the lower portion of the lower division is often shaly or arenaceous, or both. The dolomitic portions, on the other hand, are buff in color, somewhat coarser in grain, and tough. These occur both as interbedded layers in the limestone and as lateral gradations or facies of limestone beds of considerable thickness. That the formation was deposited in shallow seas is clearly indicated by several features hereinafter noted.

The brecciation effects in the formation may be grouped into three main types. First, the disturbed portion may assume the form of a small mound or reef of limestone blocks, usually in a calcareous or sandy matrix, with undisturbed layers lapping up on its flanks and filling in its depressions. These may appear at any horizon in the formation. Second, it may appear along minor faults in the Lower Saint Louis, or be confined largely to one bed of this member, due to differential movements. The latter is accompanied occasionally by the tonguelike extensions of the material forced down into the beds below, especially when the latter are softer. Third, it may embrace the major part, if not the entire formation, over an area of variable but usually limited extent. In this type the disturbance has been produced by mashing on a large scale, and the brecciation is often associated with folds and overthrust faults of small magnitude. The Pella beds are also involved to a slight extent in this disturbance, but in no instances have the underlying formations been found to exhibit signs of this type of deformation.

Regarding the origin of the brecciation, at least three periods of disturbance are believed to have operated in its production. The mounds or reef-like masses of the first type are believed to have been formed during the first period under conditions of violent wave action, possibly induced by local shallowing of the sea during deposition. The presence of local disconformities in the formation and of cross-bedded lime sands supposedly formed by the grinding up of layers already deposited is in favor of this view. Other features which suggest wave action at the time of deposition are contemporaneous erosion phenomena, wave-marks, and cross-bedding.

The brecciation of the second type was formed during the second period of deformation. The importance of this can not be definitely evaluated, since its effects are often overshadowed by the disturbance of the third type. But that this disturbance is distinct from the third is indicated by the fact that

dolomitization intervened between the two. Thus the reefs produced by the first disturbance and the shattered areas and fracture lines produced by the second are often either wholly undolomitized or are very imperfectly altered, while the undisturbed limestone about them is uniformly dolomitized. This proves that dolomitization succeeded the first and second periods of disturbance. But a later disturbance involves both the poorly dolomitized areas and the uniformly dolomitized ones, and a later series of fractures cuts the earlier ones.

Furthermore, the fact that dolomitization never affects the topmost limestone layers of the Saint Louis nor any layers of the Pella indicates that the alteration took place prior to the close of the Saint Louis. Now, since the brecciation of the second type is known to have taken place still earlier, and it is known to be confined to the Lower Saint Louis, it seems probable that this shattering may be related to the uplift which brought this division to a close.

The third period of disturbance was by far the most important. To this is ascribed the extensive mashing and shearing effects and the overthrust faulting on a small scale so common in the formation. This was influenced to a large extent by the effects of the preceding disturbances, thereby obscuring to a large degree the evidence of these. That the deformation which produced this is post-Pella, but pre-Pennsylvanian in age, is indicated by the fact that blocks of Pella limestone have been found sheared down into lower beds, and thus preserved at a locality where Pennsylvanian sandstone generally rests disconformably on these beds of a lower horizon.

The general parallelism of the strike of the faults and of the tilted layers formed at this time with certain anticlines in the region, notably the Bentonsport anticline which trends approximately north 68° west, suggests a common mode of origin of these two types of deformation.

Presented by title in the absence of the author.

VOTE OF THANKS

The following resolution presented by Professor Fairchild was adopted:

"*Resolved*, That the sincere and hearty thanks of the Society be extended to the members of the local committee who have made the efficient and satisfactory arrangements for this large and very successful meeting, especially Messrs. T. W. Vaughan and A. C. Spencer, in general charge of the local committees, and the chairmen of the subcommittees, Messrs. L. W. Stephenson, P. S. Smith, F. L. Ransome, Whitman Cross, and E. S. Bastin.

"*Resolved*, That the Society express its thanks to the George Washington University for the use of this building as a place of meeting."

The Society adjourned at 5.20 o'clock p. m.

Register of the Washington Meeting, 1915

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In addition to the foregoing, there were registered at the meeting 17 members of the Paleontological Society and 104 visitors.

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Arthur J. Collier, U. S. Geological Survey, Washington, D. C. June, 1902.
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Eugene Coste, 1943 11th St., West, Calgary, Alberta, Canada. Dec., 1906.
Alja Robinson Crook, State Museum of Natural History, Springfield, Ill. December, 1898.
*William O. Crosby, Massachusetts Institute of Technology, Boston, Mass.
Whitman Cross, U. S. Geological Survey, Washington, D. C. May, 1889.
Garry E. Culver, 1104 Wisconsin St., Stevens Point, Wis. December, 1891.
Edgar R. Cumings, Indiana University, Bloomington, Ind. August, 1901.
*Henry P. Cushing, Western Reserve University, Cleveland, Ohio..
Reginald A. Daly, Harvard University, Cambridge, Mass. December, 1905.
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*William M. Davis, Harvard University, Cambridge, Mass.
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David T. Day, 1333 F St. N. W., Washington, D. C. August, 1891.
Bashford Dean, Columbia University, New York, N. Y. December, 1910.
Frank Wilbridge De Wolf, Urbana, Ill. December, 1909.
*Joseph S. Diller, U. S. Geological Survey, Washington, D. C.
Edward V. d'Invilliers, 518 Walnut St., Philadelphia, Pa. December, 1888.
Richard E. Dodge, Teachers' College, New York, N. Y. August, 1897.
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John Alexander Dresser, 326 Notre Dame de Grace Ave., Montreal, Canada. December, 1906.
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Arthur S. Eakle, University of California, Berkeley, Cal. December, 1899.
Charles R. Eastman, American Museum of Natural History, New York, N. Y. December, 1895.
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Oliver C. Farrington, Field Museum of Natural History, Chicago, Ill. December, 1895.
Nevin M. Fenneman, University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
Clarence Norman Fenner, Geophysical Laboratory, Washington, D. C. December, 1911.

Cassius Asa Fisher, 711 Ideal Building, Denver, Colo. December, 1908.
August F. Foerste, 128 Rockwood Ave., Dayton, Ohio. December, 1899.
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*Grove K. Gilbert, U. S. Geological Survey, Washington, D. C.
Adam Capen Gill, Cornell University, Ithaca, N. Y. December, 1888.
L. C. Glenn, Vanderbilt University, Nashville, Tenn. June, 1900.
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Clarence E. Gordon, Massachusetts Agricultural College, Amherst, Mass. December, 1913.
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Walter Granger, American Museum of Natural History, New York, N. Y. December, 1911.
Ulysses Sherman Grant, Northwestern University, Evanston, Ill. Dec., 1890.
John Sharshall Grasty, University of Virginia, University, Va. Dec., 1911.
Louis C. Graton, Harvard University, Cambridge, Mass. December, 1913.
Herbert E. Gregory, Yale University, New Haven, Conn. August, 1901.
George P. Grimsley, Geological Survey of West Virginia, Martinsburg, W. Va. August, 1895.
Leon S. Griswold, Plymouth, Mass. August, 1902.
Frederic P. Gulliver, 1112 Morris Bldg., Philadelphia, Pa. August, 1895.
William F. E. R. Gurley, University of Chicago, Chicago, Ill. Dec., 1914.
Arnold Hague, U. S. Geological Survey, Washington, D. C. May, 1889.
Baird Halberstadt, Pottsville, Pa. December, 1909.
Gilbert D. Harris, Cornell University, Ithaca, N. Y. December, 1903.
John Burchmore Harrison, Georgetown, British Guiana. June, 1902.
Chris. A. Hartnagel, Education Building, Albany, N. Y. December, 1913.
John B. Hastings, 1480 High St., Denver, Colo. May, 1889.
*Erasmuth Haworth, University of Kansas, Lawrence, Kans.
Ray Vernon Hennen, West Virginia Geological Survey, Morgantown, W. Va. December, 1914.
Oscar H. Hershey, Kellogg, Idaho. December, 1909.
Richard R. Hice, Beaver, Pa. December, 1903.
*Robert T. Hill, Federal Bldg., Los Angeles, Cal.
Richard C. Hills, Denver, Colo. August, 1894.
Henry Hinds, U. S. Geological Survey, Washington, D. C. December, 1912.
*Charles H. Hitchcock, 2376 Oahu Ave., Honolulu, Hawaiian Islands.
William Herbert Hobbs, University of Michigan, Ann Arbor, Mich. August 1891.
*Levi Holbrook, P. O. Box 536, New York, N. Y.
Roy J. Holden, Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.

William Jacob Holland, Carnegie Museum, Pittsburgh, Pa. December, 1910.
Arthur Hollick, Staten Island Association of Arts and Sciences, New Brighton, S. I. August, 1898.
Thomas C. Hopkins, Syracuse University, Syracuse, N. Y. December, 1894.
William Otis Hotchkiss, State Geologist, Madison, Wis. December, 1911.
*Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.
Ernest Howe, 77 Rhode Island Ave., Newport, R. I. December, 1903.
George D. Hubbard, Oberlin College, Oberlin, Ohio. December, 1914.
Lucius L. Hubbard, Houghton, Mich. December, 1894.
Walter F. Hunt, University of Michigan, Ann Arbor, Mich. December, 1914.
Ellsworth Huntington, 222 Highland St., Milton, Mass.
Louis Hussakof, American Museum of Natural History, New York, N. Y. December, 1910.
Joseph P. Iddings, Brinklow, Md. May, 1889.
John D. Irving, Yale University, New Haven, Conn. December, 1905.
A. Wendell Jackson, 9 Desbrosses St., New York, N. Y. December, 1888.
Robert T. Jackson, 195 Bay State Road, Boston, Mass. August, 1894.
Thomas Augustus Jaggar, Jr., Hawaiian Volcano Observatory, Territory of Hawaii, U. S. A. December, 1906.
Mark S. W. Jefferson, Michigan State Normal College, Ypsilanti, Mich. December, 1904.
Edward C. Jeffrey, Harvard University, Cambridge, Mass. December, 1914.
Albert Johannsen, University of Chicago, Chicago, Ill. December, 1908.
Douglas Wilson Johnson, Columbia University, New York, N. Y. Dec., 1906.
Alexis A. Julien, South Harwich, Mass. May, 1889.
Frank James Katz, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Frederick Kay, State University of Iowa, Iowa City, Iowa. Dec., 1908.
Arthur Keith, U. S. Geological Survey, Washington, D. C. May, 1889.
*James F. Kemp, Columbia University, New York, N. Y.
Charles Rollin Keyes, 944 Fifth St., Des Moines, Iowa. August, 1890.
Edward M. Kindle, Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
Charles Townsend Kirk, University of New Mexico, Albuquerque, New Mexico. December, 1915.
Edwin Kirk, U. S. Geological Survey, Washington, D. C. December, 1912.
Cyril Workman Knight, Toronto, Ontario, Canada. December, 1911.
Adolph Knopf, U. S. Geological Survey, Washington, D. C. December, 1911.
Frank H. Knowlton, U. S. National Museum, Washington, D. C. May, 1889.
Edward Henry Kraus, University of Michigan, Ann Arbor, Mich. June, 1902.
Henry B. Kümmel, Trenton, N. J. December, 1895.
*George F. Kunz, 401 Fifth Ave., New York, N. Y.
George Edgar Ladd, State College, N. M. August, 1891.
Lawrence Morris Lambe, Department of Mines, Ottawa, Canada. Dec., 1911.
Henry Landes, University of Washington, University Station, Seattle, Wash. December, 1908.
Alfred C. Lane, Tufts College, Mass. December, 1889.
Esper S. Larsen, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1914.
Andrew C. Lawson, University of California, Berkeley, Cal. May, 1889.
Willis Thomas Lee, U. S. Geological Survey, Washington, D. C. Dec., 1903.
James H. Lees, Iowa Geological Survey, Des Moines, Iowa. December, 1914.

Charles K. Leith, University of Wisconsin, Madison, Wis. Dec., 1902.
Arthur G. Leonard, State University of North Dakota, Grand Forks, N. Dak December, 1901.
Frank Leverett, Ann Arbor, Mich. August, 1890.
Joseph Volney Lewis, Rutgers College, New Brunswick, N. J. Dec., 1906.
William Libbey, Princeton University, Princeton, N. J. August, 1899.
Waldemar Lindgren, Massachusetts Institute of Technology, Boston, Mass. August, 1890.
Miguel A. R. Lisboa, Irrigation and Water Supply Service, Rio de Janeiro, Brazil. December, 1913.
Frederick Brewster Loomis, Amherst College, Amherst, Mass. Dec., 1909.
George Davis Louderback, University of California, Berkeley, Cal. June, 1902.
Robert H. Loughridge, University of California, Berkeley, Cal. May, 1889.
Albert P. Low, Department of Mines, Ottawa, Canada. December, 1905.
Richard Swann Lull, Yale University, New Haven, Conn. December, 1909.
Samuel Washington McCallie, Atlanta, Ga. December, 1909.
Hiram Deyer McCaskey, U. S. Geological Survey, Washington, D. C. December, 1904.
Richard G. McConnell, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
Donald Francis MacDonald, U. S. Geological Survey, Washington, D. C. December, 1915.
James Rieman Macfarlane, Woodland Road, Pittsburgh, Pa. August, 1891.
William McInnes, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
Peter McKellar, Fort William, Ontario, Canada. August, 1890.
George Rogers Mansfield, 2067 Park Road N. W., Washington, D. C. December, 1909.
Curtis F. Marbut, Bureau of Soils, Washington, D. C. August, 1897.
Vernon F. Marsters, San Juancito, Honduras, C. A. August, 1892.
George Curtis Martin, U. S. Geological Survey, Washington, D. C. June, 1902.
Lawrence Martin, University of Wisconsin, Madison, Wis. December, 1909.
Edward B. Mathews, Johns Hopkins University, Baltimore, Md. Aug., 1895.
Francois E. Matthes, U. S. Geological Survey, Washington, D. C. December, 1914.
W. D. Matthew, American Museum of Natural History, New York, N. Y. December, 1903.
Thomas Poole Maynard, 1622 D. Hurt Bldg., Atlanta, Ga. December, 1914.
P. H. Mell, 165 East 10th St., Atlanta, Ga. December, 1888.
Walter C. Mendenhall, U. S. Geological Survey, Washington, D. C. June, 1902.
John C. Merriam, University of California, Berkeley, Cal. August, 1895.
*Frederick J. H. Merrill, 631 Higgins Bldg., Los Angeles, Cal.
George P. Merrill, U. S. National Museum, Washington, D. C. Dec., 1888.
Herbert E. Merwin, Geophysical Laboratory, Washington, D. C. Dec., 1914.
Arthur M. Miller, State University of Kentucky, Lexington, Ky. Dec., 1897.
Benjamin L. Miller, Lehigh University, South Bethlehem, Pa. Dec., 1904.
Willet G. Miller, Toronto, Canada. December, 1902.
William John Miller, Smith College, Northampton, Mass. December, 1909.

FRED HOWARD MOFFIT, U. S. Geological Survey, Washington, D. C. Dec., 1912.
G. A. F. MOLENGRAAF, Technical High School, Delft, Holland. December, 1913.
HENRY MONTGOMERY, University of Toronto, Toronto, Canada. Dec., 1904.
ELWOOD S. MOORE, Pennsylvania State College, State College, Pa. Dec., 1911.
MALCOLM JOHN MUNN, Clinton Bldg., Tulsa, Okla. December, 1909.
*FRANK L. NASON, West Haven, Conn.
DAVID HALE NEWLAND, Albany, N. Y. December, 1906.
JOHN F. NEWSOM, Leland Stanford, Jr., University, Stanford University, Cal. December, 1899.
WILLIAM H. NORTON, Cornell College, Mount Vernon, Iowa. December, 1895.
CHARLES J. NORWOOD, State University, Lexington, Ky. August, 1894.
IDA HELEN OGILVIE, Barnard College, Columbia University, New York, N. Y. December, 1906.
CLEOPHAS C. O'HARRA, South Dakota School of Mines, Rapid City, S. Dak. December, 1904.
DANIEL WEBSTER OHERN, University of Oklahoma, Norman, Okla. Dec., 1911.
EZEQUIEL ORDONEZ, 2 a General Prim 43, Mexico, D. F., Mex. August, 1896.
EDWARD ORTON, JR., Geological Survey of Ohio, Columbus, Ohio. Dec., 1909.
HENRY F. OSBORN, American Museum of Natural History, New York, N. Y. August, 1894.
SIDNEY PAIGE, U. S. Geological Survey, Washington, D. C. December, 1911.
CHARLES PALACHE, Harvard University, Cambridge, Mass. August, 1897.
WILLIAM A. PARKS, University of Toronto, Toronto, Canada. December, 1906.
*HORACE B. PATTON, Colorado School of Mines, Golden, Colo.
FREDERICK B. PECK, Lafayette College, Easton, Pa. August, 1901.
RICHARD A. F. PENROSE, JR., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.
GEORGE H. PERKINS, University of Vermont, Burlington, Vt.; State Geologist. June, 1902.
JOSEPH H. PERRY, 276 Highland St., Worcester, Mass. December, 1888.
OLAF AUGUST PETERSON, Carnegie Museum, Pittsburgh, Pa. December, 1910.
WILLIAM CLIFTON PHALEN, U. S. Geological Survey, Washington, D. C. December, 1912.
ALEXANDER H. PHILLIPS, Princeton University, Princeton, N. J. Dec., 1914.
LOUIS V. PIRSSON, Yale University, New Haven, Conn. August, 1894.
JOSEPH E. POGUE, Northwestern University, Evanston, Ill. December, 1911.
JOSEPH HYDE PRATT, North Carolina Geological Survey, Chapel Hill, N. C. December, 1898.
LOUIS M. PRINDLE, U. S. Geological Survey, Washington, D. C. Dec., 1912.
*CHARLES S. PROSSER, Ohio State University, Columbus, Ohio.
WILLIAM FREDERICK PROUTY, University of Alabama, University, Ala. December, 1911.
*RAPHAEL PUMPELLY, Newport, R. I.
ALBERT HOMER PURDUE, State Geological Survey, Nashville, Tenn. Dec., 1904.
FREDERICK LESLIE RANSOME, U. S. Geological Survey, Washington, D. C. August, 1895.
PERCY EDWARD RAYMOND, Museum of Comparative Zoölogy, Cambridge, Mass December, 1907.
CHESTER A. REEDS, American Museum of Natural History, New York, N. Y. December, 1913.

Harry Fielding Reid, Johns Hopkins University, Baltimore, Md. Dec., 1892.
William North Rice, Wesleyan University, Middletown, Conn. August, 1890.
John Lyon Rich, University of Illinois, Urbana, Ill. December, 1912.
Charles H. Richardson, Syracuse University, Syracuse, N. Y. Dec., 1899.
George Burr Richardson, U. S. Geological Survey, Washington, D. C. December, 1908.
Heinrich Ries, Cornell University, Ithaca, N. Y. December, 1893.
Elmer S. Riggs, Field Museum of Natural History, Chicago, Ill. Dec., 1911.
Jesse Perry Rowe, University of Montana, Missoula, Mont. December, 1911.
Rudolph Ruedemann, Albany, N. Y. December, 1905.
John Joseph Rutledge, Experiment Station, Pittsburgh, Pa. Dec., 1911.
Orestes H. St. John, 1141 Twelfth St., San Diego, Cal. May, 1889.
*Rollin D. Salisbury, University of Chicago, Chicago, Ill.
Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.
Thomas Edmund Savage, University of Illinois, Urbana, Ill. December, 1907.
Frank C. Schrader, U. S. Geological Survey, Washington, D. C. Aug., 1901.
Charles Schuchert, Yale University, New Haven, Conn. August, 1895.
Alfred Reginald Schultz, U. S. Geological Survey, Washington, D. C. December, 1912.
William B. Scott, Princeton University, Princeton, N. J. August, 1892.
Arthur Edmund Seaman, Michigan College of Mines, Houghton, Mich. December, 1904.
Henry M. Seely, Middlebury College, Middlebury, Vt. May, 1889.
Elias H. Sellards, Tallahassee, Fla. December, 1905.
Joaquim Candido da Costa Seña, State School of Mines, Ouro Preto, Brazil. December, 1908.
Millard K. Shaler, 4 Bishopsgate E. C., London, England. December, 1914.
George Burbank Shattuck, Vassar College, Poughkeepsie, N. Y. Aug., 1899.
Eugene Wesley Shaw, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Solon Shedd, State College of Washington, Pullman, Wash. Dec., 1904.
Edward M. Shepard, 1403 Benton Ave., Springfield, Mo. August, 1901.
Bohumil Shimek, University of Iowa, Iowa City, Iowa. December, 1904.
Hervey Woodburn Shimer, Massachusetts Institute of Technology, Boston, Mass. December, 1910.
Claude Ellsworth Siebenthal, U. S. Geological Survey, Washington, D. C. December, 1912.
*Frederick W. Simonds, University of Texas, Austin, Texas.
William John Sinclair, Princeton University, Princeton, N. J. Dec., 1906.
Joseph Theophilus Singewald, Johns Hopkins University, Baltimore, Md. December, 1911.
Earle Sloan, Charleston, S. C. December, 1908.
Burnett Smith, Syracuse University, Skaneateles, N. Y. December, 1911.
Carl Smith, U. S. Geological Survey, Washington, D. C. December, 1912.
*Eugene A. Smith, University of Alabama, University, Ala.
George Otis Smith, U. S. Geological Survey, Washington, D. C. Aug., 1897.
Philip S. Smith, U. S. Geological Survey, Washington, D. C. Dec., 1909.
Warren Du Pré Smith, University of Oregon, Eugene, Oregon. Dec., 1909.
W. S. Tangier Smith, Lodi, Cal. June, 1902.

*John C. Smock, Trenton, N. J.

Charles H. Smyth, Jr., Princeton University, Princeton, N. J. Aug., 1892.

Henry L. Smyth, Harvard University, Cambridge, Mass. August, 1894.

Arthur Coe Spencer, U. S. Geological Survey, Washington, D. C. Dec., 1896.

*J. W. Spencer, 2019 Hillyer Place. Washington, D. C.

Frank Springer, U. S. National Museum, Washington, D. C. December, 1911.

Josiah E. Spurr, Bullitt Bldg., Philadelphia, Pa. December, 1894.

Joseph Stanley-Brown, 26 Exchange Place, New York, N. Y. August, 1892.

Timothy William Stanton, U. S. National Museum, Washington, D. C. August, 1891.

Clinton Raymond Stauffer, University of Minnesota, Minneapolis, Minn. December, 1911.

Lloyd William Stephenson, U. S. Geological Survey, Washington, D. C. December, 1911.

*John J. Stevenson, 215 West 101st St., New York, N. Y.

Ralph Walter Stone, U. S. Geological Survey, Washington, D. C. Dec., 1912.

George Willis Stose, U. S. Geological Survey, Washington, D. C. Dec., 1908.

Charles Kephart Swartz, Johns Hopkins University, Baltimore, Md. December, 1908.

Stephen Taber, University of South Carolina, Columbia, S. C. Dec., 1914.

Joseph A. Taff, 781 Flood Building, San Francisco, Cal. August, 1895.

Mignon Talbot, Mount Holyoke College, South Hadley, Mass. Dec., 1913.

James E. Talmage, University of Utah, Salt Lake City, Utah. Dec., 1897.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

*James E. Todd, 1224 Rhode Island St., Lawrence, Kans.

Cyrus Fisher Tolman, Jr., Leland Stanford, Jr., University, Stanford University, Cal. December, 1909.

Arthur C. Trowbridge, State University of Iowa, Iowa City, Iowa. December, 1913.

*Henry W. Turner, 209 Alaska Commercial Building, San Francisco, Cal.

William H. Twenhofel, University of Kansas, Lawrence, Kans. Dec., 1913.

Mayville William Twitchell, State Geological Survey, Trenton, N. J. December, 1911.

Joseph B. Tyrrell, Room 534, Confederation Life Building, Toronto, Canada. May, 1889.

Johan A. Udden, University of Texas, Austin, Texas. August, 1897.

Edward O. Ulrich, U. S. Geological Survey, Washington, D. C. Dec., 1903.

Joseph B. Umpleby, U. S. Geological Survey, Washington, D. C. Dec., 1913.

*Warren Upham, Minnesota Historical Society, Saint Paul, Minn.

*Charles R. Van Hise, University of Wisconsin, Madison, Wis.

Frank Robertson Van Horn, Case School of Applied Science, Cleveland, Ohio. December, 1898.

Gilbert van Ingen, Princeton University, Princeton, N. J. December, 1904.

Thomas Wayland Vaughan, U. S. Geological Survey, Washington, D. C. August, 1896.

Arthur Clifford Veach, 7 Richmond Terrace, Whitehall, S. W., London, England. December, 1906.

*Anthony W. Vogdes, 2425 First St., San Diego, Cal.

*M. EDWARD WADSWORTH, School of Mines, University of Pittsburgh, Pittsburgh, Pa.
*CHARLES D. WALCOTT, Smithsonian Institution, Washington, D. C.
THOMAS L. WALKER, University of Toronto, Toronto, Canada. Dec., 1903.
CHARLES H. WARREN, Massachusetts Institute of Technology, Boston, Mass. December, 1901.
HENRY STEPHENS WASHINGTON, Geophysical Laboratory, Washington, D. C. August, 1896.
THOMAS L. WATSON, University of Virginia, Charlottesville, Va. June, 1900.
CHARLES E. WEAVER, University of Washington, Seattle, Wash. Dec., 1913.
WALTER H. WEED, 29 Broadway, New York, N. Y. May, 1889.
CARROLL HARVEY WEGEMANN, U. S. Geological Survey, Washington, D. C. December, 1912.
SAMUEL WEIDMAN, Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.
STUART WELLER, University of Chicago, Chicago, Ill. June, 1900.
LEWIS G. WESTGATE, Ohio Wesleyan University, Delaware, Ohio. Aug., 1894.
EDGAR THEODORE WHERRY, U. S. National Museum, Washington, D. C. December, 1915.
DAVID WHITE, U. S. National Museum, Washington, D. C. May, 1889.
*ISRAEL C. WHITE, Morgantown, W. Va.
GEORGE REBER WIELAND, Yale University, New Haven, Conn. December, 1910.
FRANK A. WILDER, North Holston, Smyth County, Va. December, 1905.
*EDWARD H. WILLIAMS, JR., Woodstock, Vt.
*HENRY S. WILLIAMS, Cornell University, Ithaca, N. Y.
IRA A. WILLIAMS, Oregon School of Mines, Corvallis, Ore. December, 1905.
BAILEY WILLIS, Leland Stanford, Jr., University, Cal. December, 1889.
ALFRED W. G. WILSON, Department of Mines, Ottawa, Canada. June, 1902.
ALEXANDER N. WINCHELL, University of Wisconsin, Madison, Wis. Aug., 1901.
*HORACE VAUGHN WINCHELL, 826 First National Society Bldg., Minneapolis, Minn.
*ARTHUR WINSLOW, 131 State St., Boston, Mass.
JOHN E. WOLFF, Harvard University, Cambridge, Mass. December, 1889.
JOSEPH E. WOODMAN, New York University, New York, N. Y. Dec., 1905.
ROBERT S. WOODWARD, Carnegie Institution of Washington, Washington, D. C. May, 1889.
JAY B. WOODWORTH, Harvard University, Cambridge, Mass. December, 1895.
CHARLES WILL WRIGHT, Ingurtosu, Arbus, Sardinia, Italy. December, 1909.
FREDERIC E. WRIGHT, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.
*G. FREDERICK WRIGHT, Oberlin Theological Seminary, Oberlin, Ohio.
GEORGE A. YOUNG, Geological Survey of Canada, Ottawa, Canada. Dec., 1905.

CORRESPONDENTS DECEASED

HERMAN CREDNER. Died July 22, 1913.
A. MICHEL-LÉVY. Died September, 1911.
H. ROSENBUSCH. Died January 20, 1914.
EDWARD SUESS. Died April 20, 1914.
TH. TSCHERNYSCHEW. Died Jan. 15, 1914
FERDINAND ZIRKEL. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*CHAS. A. ASHBURNER. Died Dec. 24, 1889.
ALFRED E. BARLOW. Died May 28, 1914.
CHARLES E. BEECHER. Died Feb. 14, 1904.
ALBERT S. BICKMORE. Died Aug. 12, 1914.
WM. PHIPPS BLAKE. Died May 21, 1910.
AMOS BOWMAN. Died June 18, 1894.
ERNEST R. BUCKLEY. Died Jan. 19, 1912.
*SAMUEL CALVIN. Died April 17, 1911.
FRANKLIN R. CARPENTER. Died April 1, 1910.
*J. H. CHAPIN. Died March 14, 1892.
*EDWARD W. CLAYPOLE. Died Aug. 17, 1901.
*THEO. B. COMSTOCK. Died July 26, 1915.
GEORGE H. COOK. Died Sept. 22, 1889.
*EDWARD D. COPE. Died April 12, 1897.
ANTONIO DEL CASTILLO. Died Oct. 28, 1895.
*JAMES D. DANA. Died April 14, 1895.
GEORGE M. DAWSON. Died March 2, 1901.
SIR J. WM. DAWSON. Died Nov. 19, 1899.
ORVILLE A. DERBY. Died Nov. 27, 1915.
CLARENCE E. DUTTON. Died Jan. 4, 1912.
*WILLIAM B. DWIGHT. Died Aug. 29, 1906.
*GEORGE H. ELDRIDGE. Died June 29, 1905.
*SAMUEL F. EMMONS. Died March 28, 1911.
WM. M. FONTAINE. Died April 29, 1913.
*ALBERT E. FOOTE. Died October 10, 1895.
*PERSIFOR FRAZER. Died April 7, 1909.
*HOMER T. FULLER. Died Aug. 14, 1908.
N. J. GIROUX. Died November 30, 1891.
*CHRISTOPHER W. HALL. Died May 10, 1911.
*JAMES HALL. Died August 7, 1898.
JOHN B. HATCHER. Died July 3, 1904.
*ROBERT HAY. Died December 14, 1895.
C. WILLARD HAYES. Died Feb. 9, 1916.
*ANGELO HEILPRIN. Died July 17, 1907.
FRANK A. HILL. Died July 13, 1915.
*JOSEPH A. HOLMES. Died July 13, 1915.
DAVID HONEYMAN. Died October 17, 1889.
*EDWIN E. HOWELL. Died April 16, 1911.
*HORACE C. HOVEY. Died July 27, 1914.
THOMAS S. HUNT. Died Feb. 12, 1892.
*ALPHEUS HYATT. Died Jan. 15, 1902.
THOMAS M. JACKSON. Died Feb. 3, 1912.
*JOSEPH F. JAMES. Died March 29, 1897.
WILBUR C. KNIGHT. Died July 28, 1903.
RALPH D. LACOE. Died February 5, 1901.
J. C. K. LAFLAMME. Died July 6, 1910.
DANIEL W. LANGTON. Died June 21, 1909.
*JOSEPH LE CONTE. Died July 6, 1901.
*J. PETER LESLEY. Died June 2, 1903.
HENRY MCCALLEY. Died Nov. 20, 1904.
*W J MCGEE. Died September 4, 1912.
OLIVER MARCY. Died March 19, 1899.
OTHNIEL C. MARSH. Died March 18, 1899.
JAMES E. MILLS. Died July 25, 1901.
*HENRY B. NASON. Died January 17, 1895.
*PETER NEFF. Died May 11, 1903.
*JOHN S. NEWBERRY. Died Dec. 7, 1892.
WILLIAM H. NILES. Died Sept. 12, 1910.
*EDWARD ORTON. Died October 16, 1899.
*AMOS O. OSBORN. Died March, 1911.
*RICHARD OWEN. Died March 24, 1890.
SAMUEL L. PENFIELD. Died Aug. 14, 1906.
DAVID P. PENHALLOW. Died Oct. 20, 1910.
*FRANKLIN PLATT. Died July 24, 1900.
WILLIAM H. PETTEE. Died May 26, 1904.
*JOHN W. POWELL. Died Sept. 23, 1902.
*ISRAEL C. RUSSELL. Died May 1, 1906.
*JAMES M. SAFFORD. Died July 3, 1907.
*CHARLES SCHAEFFER. Died Nov. 23, 1903.
*NATHANIEL S. SHALER. Died April 10, 1906.
WILLIAM J. SUTTON. Died May 9, 1915.
RALPH S. TARR. Died March 21, 1912.
WILLIAM G. TIGHT. Died Jan. 15, 1910.
CHARLES WACHSMUTH. Died Feb. 7, 1896.
THOMAS C. WESTON. Died July 20, 1910.
THEODORE G. WHITE. Died July 7, 1901.
*ROBERT P. WHITFIELD. Died April 6, 1910.
*GEORGE H. WILLIAMS. Died July 12, 1894.
*J. FRANCIS WILLIAMS. Died Nov. 9, 1891.
ARTHUR B. WILMOTT. Died May 8, 1914.
*ALEXANDER WINCHELL. Died Feb. 19, 1891.
*NEWTON WINCHELL. Died May 1, 1914.
ALBERT A. WRIGHT. Died April 2, 1905.
WILLIAM S. YEATES. Died Feb. 19, 1908.

Summary

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 27, PP. 139-174 MARCH 31, 1916
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE SEVENTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT WASHINGTON, DISTRICT OF COLUMBIA, DECEMBER 29, 30, AND 31, 1915.

R. S. BASSLER, *Secretary*

CONTENTS

Session of Wednesday, December 29

The general session of the Society was called to order at 9.30 a. m., December 29, in a lecture-room of the George Washington University Medical School, by President Edward O. Ulrich, who, after welcoming the members to Washington, opened the business session by calling for the report of the Council.

REPORT OF THE COUNCIL

To the Paleontological Society in Seventh Annual Meeting assembled:

The first meeting of this year's Council was held at Philadelphia, Pennsylvania, December 31, 1914, immediately following the adjournment of the Society on that day. Routine business and the consideration of the ticket for the following year were considered at this meeting, but since then the business of the Society has, as usual, been transacted by correspondence. The following reports of officers give a résumé of the administration for the Society's seventh year.

Secretary's Report

To the Council of the Paleontological Society:

The proceedings of the sixth annual meeting of the Society, held at Philadelphia, Pennsylvania, December 29, 30, and 31, 1914, have been published in volume 26, pages 141-170 of the Bulletin of the Geological Society of America, and distributed to the members in March, 1915. Besides this publication, the scientific papers of the Society published in this Bulletin during the year are eight in number and occupy the greater part of number 3 and a portion of number 4, volume 26.

The Council's proposed nomination for officers and announcement that the seventh annual meeting of the Society would occur at Washington, D. C., at the invitation of the local members, were forwarded to the members on March 10, 1915.

Membership.—During the year the Society has lost by death Dr. Orville A. Derby, of the Geological Survey of Brazil, so well known for his long service and researches on the geology of that country. Two resignations have occurred during the year. The ten candidates elected at the sixth annual meeting have been placed on the rolls, making the present enrolment 164. Eight candidates are under consideration for the present meeting.

Pacific Coast Section.—The sixth annual meeting of the Pacific Coast Section of the Society was held in Bacon Hall, University of California, at Berkeley, on Saturday, February 27, 1915. Eighteen papers, dealing

with both the Vertebrate and Invertebrate Paleontology and Stratigraphy of the West Coast, were read at this meeting. The minutes of this section are printed on pages 168 to 174 of this Bulletin.

Of particular interest during the year was the special meeting of the Society, August 3-6, 1915, at the University of California and at Stanford University. This meeting included

A symposium on a general consideration of the paleontological criteria used in determining time relations, participated in by Doctors Ulrich, Matthew, Schuchert, and Knowlton;

(2) A comparison between the Triassic of the Pacific area and other parts of the world, under the direction of Prof. James Perrin Smith;

(3) A correlation between the Cretaceous of the Pacific area and that of other parts of the world, under the direction of Doctor Stanton; and

(4) A correlation between the Miocene of the Pacific region and that of other areas of the world, with Professor Osborn in charge.

Following the scientific meeting of the Society, several excursions were made to points of paleontological and stratigraphic interest in California. The minutes of this special meeting have been published in the Bulletin of the Geological Society of America, volume 26, number 4, pages 409-418.

Respectfully submitted, R. S. Bassler,
Secretary.

Washington, D. C., *December* 28, 1915.

Treasurer's Report

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 21, 1915:

RECEIPTS

Cash on hand December 1, 1914		$259.98	
Membership fees, 1914 (7)		21.00	
Membership fees, 1915 (73)		219.20	
			$500.18

EXPENDITURES

Treasurer's office:			
Postage	$4.50		
Printing and stationery	5.75		
		$10.25	
Secretary's office:			
Secretary's allowance	50.00		
Expenses	39.15		
		89.15	

Pacific Coast Section:			
Secretary's expenses	17.61		
		17.61	
			$117.01
Balance on hand December 21, 1915			$383.17
Net increase in funds			$123.19
Outstanding dues, 1914 (3)		$9.00	
Outstanding dues, 1915 (6)		18.00	
			$27.00

Respectfully submitted, RICHARD S. LULL, *Treasurer.*

NEW HAVEN, CONNECTICUT, *December* 21, 1915.

APPOINTMENT OF AUDITING COMMITTEE

The appointment of a committee to audit the Treasurer's accounts being next in order, President Ulrich selected Stuart Weller and W. J. Sinclair.

ELECTION OF OFFICERS AND MEMBERS

The results of the ballot for officers for 1916 and election of members was the next matter of business and was announced by the Secretary as follows:

OFFICERS FOR 1916

President:

RUDOLPH RUEDEMANN, Albany, N. Y.

First Vice-President:

T. WAYLAND VAUGHAN, Washington, D. C.

Second Vice-President:

AUGUST F. FOERSTE, Dayton, Ohio

Third Vice-President:

E. B. BRANSON, Columbia, Mo.

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

RICHARD S. LULL, New Haven, Conn.

Editor:

CHARLES R. EASTMAN, New York City

MEMBERS

L. A. ADAMS, Colorado State Teachers' College, Greeley, Colo.
EDWIN J. ARMSTRONG, 954 West Ninth street, Erie, Pa.
C. WYTHE COOKE, U. S. Geological Survey, Washington, D. C.
J. J. GALLOWAY, Dept. of Geology, Indiana University, Bloomington, Ind.
R. C. MOORE, Dept. of Geology, University of Chicago, Chicago, Ill.
WILLIAM H. SHIDELER, Dept. of Geology, Miami University, Oxford, Ohio.
A. O. THOMAS, Dept. of Geology, University of Iowa, Iowa City, Iowa.
WENDELL P. WOODRING, Dept. of Geology, Johns Hopkins Univ., Baltimore, Md.

ELECTION OF NEW MEMBERS

The Secretary then announced that the Council favored the election to membership in the Paleontological Society of Dr. Willis T. Lee and Dr. C. E. Weaver, both Fellows of the Geological Society of America. Dr. John M. Clarke moved that Prof. Joseph Barrell also be elected to membership in the Society. After unanimous vote of the members present, the Secretary was instructed to add the names of Doctor Lee, Doctor Weaver, and Professor Barrell to the Society's rolls.

The President next directed the attention of the Society to two nominations for membership—Homer Hamlin and Reginald C. Stover—which had been acted on favorably by the Council. Before the election of these two was concluded, Professor Weller proposed the name of K. F. Mather, Professor Van Ingen that of B. F. Howell, and Doctor Grabau that of S. H. Knight. After a brief discussion, it was voted by all members present that the by-laws be suspended, and that these five nominees be elected to membership in the Society. The names and a brief statement regarding the members just elected follow:

HOMER HAMLIN, City Engineer, Los Angeles, Cal. Engaged in invertebrate paleontology. Proposed by J. C. Merriam, E. L. Packard, and Ralph Arnold.

BENJAMIN F. HOWELL, B. S. (1913) and A. M. (1915) Princeton University. Instructor of geology at Princeton University. Engaged in invertebrate paleontology, especially in study of Cambrian faunas. Proposed by Gilbert Van Ingen and William J. Sinclair.

SAMUEL H. KNIGHT, A. B. University of Wyoming. Graduate student, Department of Geology, Columbia University, and assistant professor of geology, University of Wyoming. Engaged in stratigraphic paleontology. Proposed by A. W. Grabau, Marjorie O'Connel, and R. S. Bassler.

KIRTLEY F. MATHER, B. S. (1909) Denison, Ph. D. (1915) Chicago, assistant professor of geology, Queen's University, Kingston, Ontario. Engaged in invertebrate paleontology. Proposed by Stuart Weller and R. S. Bassler.

REGINALD C. STOVER, Geologist, Standard Oil Building, San Francisco, Cal. Engaged in vertebrate and invertebrate paleontology. Proposed by Ralph Arnold, J. C. Merriam, and E. L. Packard.

MEMORIAL OF ORVILLE A. DERBY

Dr. John M. Clarke then spoke of the loss to the Society by the death of Dr. Orville A. Derby, Chief of the Geological Survey of Brazil, and gave a personal appreciation of his character and life work resulting from his long acquaintance with Doctor Derby and from their mutual interest in Devonian paleontology. The memorial to Doctor Derby by Professor Branner is published as pages 15-21 of this number.

ANNOUNCEMENTS

It was then announced that the Council had voted favorably on the request of the Treasurer to transfer $300 of the Society's funds from the Second National Bank of New Haven to the Connecticut Savings Bank of the same place in order that this sum should bear interest.

No further business remaining, the Society proceeded in general session to the reading of the papers on general paleontology.

PRESENTATION OF GENERAL PAPERS

The first paper of the session was presented by the author and illustrated by lantern slides and specimens; 10 minutes.

PRESENCE OF A MEDIAN EYE IN TRILOBITES

BY RUDOLPH RUEDEMANN

(*Abstract*)

The median or parietal eye which is present in lower crustaceans and also in the phyllopods with which the trilobites are usually compared is, in the majority of the Ordovicic and Siluric trilobites, recognizable in a tubercle on the glabella. This tubercle has long been known to exist in all asaphids on otherwise wholly smooth carapaces (see Schmidt, Revision der ostbaltischen silurischen Trilobites) and is well known in Cryptolithus (Trinucleus) and others; its regular occurrence is recorded in the literature of more than thirty genera. It has been found by us to possess two distinct lenses, similar to the median eye of the eurypterids, in *Ptychopyge rimulosa*; in others, as in Cryptolithus, but one lens; and in most cases it is simply a transparent spot of the crust, often thinner, sometimes thickened lenslike, more or less elevated, corresponding in these features to the prevailing character of the median eye in the other crustaceans. Even as simple tubercle its visual function and nature of a median eye is proven by its position between the lateral eyes, as in the other arthropods—that is, nearest to the brain ganglia—and invariably on the highest spot of the glabella, which is the most favorable position for its visual function. The eye tubercle is, as a rule, relatively largest in the earlier growth stages; in some species, as *Isotelus gigas*, it disappears entirely with maturity. In some Siluric and most Devonic genera, especially the Phacopida, the median eye has, corresponding to the strong development of the lateral eyes, been more

or less reduced, but may often be still recognizable in the interior mold as a pit, due to the inward growth of the lenslike thickening of the crust. Per contra, it is most strongly developed in the so-called "blind" trilobites, where the lateral eyes are reduced or lost. The more important Cambric families still lack the eye tubercle, but in young specimens of *Elliptocephala asaphoides* the median eye was found to possess the primitive forms of two separate transparent spots or lenslike thickenings on the front part of the glabella that do not project above the surface.

It has been recognized by zoologists for some time that the trilobites normally should possess median or parietal eyes.

The "ocelli" of Harpes, Cryptolithus, and Dionide are reduced lateral eyes with traces of the true suture.

Following Doctor Ruedemann's paper was one on the general subject of reef deposits, which brought forth a discussion, participated in by Messrs. Ulrich, Van Ingen, Schuchert, Berry, and the author. Illustrated by lantern slides; 20 minutes.

IMPORTANCE OF "CORAL REEFS" AND REEF DEPOSITS IN THE FORMATION OF PALEOZOIC LIMESTONES

BY THOMAS C. BROWN

(*Abstract*)

In the Paleozoic limestones a number of coral reefs and reef-like structures have been described from various horizons. In the present-day reef areas it has been found that a large part of the calcium carbonate deposited is precipitated chemically by reactions brought about by micro-organisms. There are many Paleozoic horizons where similar conditions prevailed. This is clearly shown by the nature of the sediments and by the structural relations of the strata thus formed.

Many of the Paleozoic limestones which have generally been considered to be the products of the mechanical attrition of shells and other organic structures, or of the disintegration of preexisting limestones, show by their internal structure and physical features that they were formed under conditions similar to the reefs of today.

The following paper on the distribution of corals was next in order and was discussed by Messrs. Ulrich, J. M. Clarke, Van Ingen, Ami, and the author; 20 minutes.

DISTRIBUTION AND INFERRED MIGRATION OF AMERICAN MIDDLE AND UPPER DEVONIC CORALS

BY AMADEUS W. GRABAU

(*Abstract*)

While monographing the Michigan Devonic corals light was obtained on the probable routes of migration between America and Eurasia, these being apparently across the North Polar region during Onondaga time and via Alaska and the northwest Canadian region subsequently.

Several papers bearing on mutations were then read, the first of these being the following, which was discussed by Messrs. Ulrich, Grabau, Schuchert, Ruedemann, and Loomis, with replies by the author:

MUTATIONS OF WAAGEN, MUTATIONSRICHTUNG OF NEUMAYR, MUTANTS OF DE VRIES: RELATIONS OF THESE PHENOMENA IN EVOLUTION

BY HENRY FAIRFIELD OSBORN

The second paper on mutations, by A. W. Grabau, was withdrawn, so that it could be discussed in the exhibition room in connection with charts and other illustrations.

SYSTEMATIC RANK OF MUTATIONS AND SUBMUTATIONS IN ORTHOGENETIC SERIES AMONG THE INVERTEBRATES

BY AMADEUS W. GRABAU

(Abstract)

It is shown that mutations and submutations may vary in systematic value, being of varietal specific or even generic rank, in accordance with the degree of fixity attained by the various morphological stages of development in different genetic series.

A second paper by the same author was next in order, but was again withdrawn, so that it could be discussed in the exhibition room, where illustrative charts were available.

CLASSIFICATION OF THE TETRASEPTATA, WITH SOME REMARKS ON PARALLELISM IN DEVELOPMENT IN THIS GROUP: A STUDY IN ORTHOGENESIS

BY AMADEUS W. GRABAU

(Abstract)

The paper offers amended and revised classification of the Tetraseptata (Tetracoralla) and shows how many of the common genera of this group are in reality polyphyletic circuli, and that a recognition of the law of parallelism in development requires a redefining of these genera.

The final paper of the morning then followed and was discussed by H. M. Ami and Rudolph Ruedemann, with replies by the author.

GUELPH FORMATION OF ONTARIO

BY M. Y. WILLIAMS

(Abstract)

The Guelph formation of southwestern Ontario, as originally defined, consists of about 185 feet of saccharoidal dolomite. From information obtained

from the records of bore-holes, the formation evidently grades upward into the overlying Salina formation. Conformably beneath the Guelph are 30 feet or more of thin-bedded dolomites, recently called by the writer the "Eramosa beds." These are generally argillaceous and commonly bituminous and have been defined as the top of the Lockport formation. These beds are persistent almost throughout the Guelph area of Ontario, and indicate by their lithological characters, as well as by the meager fauna contained, transitional conditions between Lockport and Guelph sedimentation.

Eastward, toward the Niagara River, the Guelph formation is greatly reduced in thickness and the underlying thin beds are illy defined. Northward, on the Bruce Peninsula, the lower Guelph beds contain a cephalopod-lamellibranch fauna, closely related to the fauna of the Racine beds of Wisconsin. The typical Guelph occurs along the west shore of the Bruce Peninsula and on the islands to the north as far as the extreme western end of Fitzwilliam Island. Beds belonging either to the Upper Lockport or Lower Guelph also occur on the south shore of the western end of Manitoulin Island.

The meeting then adjourned for luncheon.

PRESIDENTIAL ADDRESS

At 2 p. m. the Society met in conjunction with the Geological Society of America to hear the address of E. O. Ulrich, the retiring President of the Paleontological Society, entitled

THE USE OF FOSSILS IN CORRELATION

Following this address the Society met in two sections, the Vertebrate Section in the library of the Medical School and a Section of Invertebrate and General Paleontology continuing in the general-session room.

The minutes of the Section of Vertebrate Paleontology follow:

SECTION OF VERTEBRATE PALEONTOLOGY

The Section of Vertebrate Paleontology, with Prof. F. B. Loomis in the chair, held separate sessions for the presentation of special papers, commencing Wednesday afternoon, December 29, at 3.30 o'clock, after the presidential address and the completion of the general papers in the Society. Dr. W. J. Sinclair was requested to act as secretary. The following papers were presented:

PHYLOGENETIC REVIEW OF EXTINCT AND RECENT ANTHROPOIDS, WITH SPECIAL REFERENCE TO THE EVOLUTION OF THE HUMAN DENTITION

BY W. K. GREGORY

(*Abstract*)

Of the anthropoids from the Lower Oligocene of Egypt *Parapithecus* Schlosser is known from a very small lower jaw and complete dentition. In

some characters it recalls the Eocene Anaptomorphidæ, but the pattern of the premolars and molars is fundamentally similar to that of its contemporary, *Propliopithecus* Schlosser, which is a true anthropoid, much smaller than the gibbon and foreshadowing the *Pliopithecus*-gibbon line as well as *Dryopithecus*, the Chimpanzee, and the Gorilla-man group, as held by Schlosser. *Dryopithecus* of the Upper Miocene includes six species—three from India, recently described by Pilgrim, and three from Europe, known chiefly from molar teeth and lower jaws. To the writer *D. punjabicus* and the later *D. rhenanus* appear to be ancestral to the Chimpanzee, while *D. chinjiensis* and perhaps *D. fontani* appear to lead to the Gorilla.

Palæosimia Pilgrim, from India, is known from a third upper molar which foreshadows that of the Orang. *Sivapithecus* Pilgrim, from the Chinji zone of the Lower Siwalks (Upper Miocene) strongly suggests the Hominidæ in its wide molars and bicuspids, but retains the primitive apelike canines. In the *Dryopithecus* group (including *Sivapithecus*) there is a very special resemblance and affinity in the patterns of all the upper and lower premolars and molars to those of the Hominidæ, which family may well have been derived from some Upper Miocene member of that group. The retraction of the jaws and the reduction in size of the canines and front lower premolars in the Hominidæ are retrogressive characters, as is also the reduction in the pattern of the second and third upper molars from a more quadritubercular to a tritubercular condition.

Paper discussed by Professor Osborn, Doctor Miller, and Doctor Case. Remarks by Professor Osborn on *Pan vetus* from Third Interglacial of Taubach (a Chimpanzee of Pleistocene age).

ADDITIONAL CHARACTERS OF TYRANNOSAURUS AND ORNITHOMIMUS

BY HENRY FAIRFIELD OSBORN

(Abstract)

The complete skeletons of *Tyrannosaurus* and *Ornithomimus* recently secured and mounted in the American Museum of Natural History render possible a thorough comparison of these two extreme types of adaptation. *Tyrannosaurus* is highly specialized, both in the skull, fore limb, and the hind limb, as a flesh-eating type, capable of overcoming and devouring the most formidably defended prey; in other words, it is an example of harmonious adaptation throughout.

The discovery of the skull and fore-limb structure of *Ornithomimus* has afforded one of the greatest surprises in the whole history of vertebrate paleontology. Although descended from the same stock as *Tyrannosaurus*, as indicated by many common points of structure, as well as by its relationship to *Ornitholestes* of the Lower Cretaceous, this animal has diverged as widely as possible from the raptorial type. The chief feature is the entire absence of teeth and the modification of the skull and jaws into a beak closely analogous to that of the struthious birds. The feet have entirely lost their prehensile or raptorial powers and developed cursorial adaptations very similar to those of the rhea and the cassowary.

Regarding the skull and the feet alone, it might be possible to regard this as an ostrich-like or struthioid dinosaur and browser, adapted to subsisting on

shrubs and buds and to rapid flight from enemies; but the fore limb presents very great difficulty, since it has extremely long and slender digits terminating in three laterally compressed digits with claws, somewhat resembling those of tree-sloths and ant-eaters. The bones of the shoulder have, however, no fossorial powers or musculature and were evidently incapable of digging.

Three forms of adaptation have been suggested. First, that this arm was used for pulling down branches of trees in browsing; second, that it was used in scratching open ant-hills; third, that it was used in scratching sand along the seashore in search for crustaceans. None of these hypotheses appears adequate or to afford a harmonious interpretation of the adaptations of this remarkable animal.

Discussion by Mr. Gilmore and Doctor Case, the latter suggesting possible ant-eating habits for *Ornithomimus.*

CRITERIA FOR THE DETERMINATION OF SPECIES IN THE SAUROPODS, WITH DESCRIPTION OF A NEW SPECIES OF APATOSAURUS

BY CHARLES C. MOOK

(*Abstract*)

The size and structural variations of the skeletal elements in Sauropod dinosaurs were discussed and the specific characters of a new species of *Apatosaurus* were given.

Discussion by Professor Osborn and Doctor Loomis.

PELVIS AND SACRUM OF CAMARASAURUS

BY HENRY FAIRFIELD OSBORN

(*Abstract*)

A series of diagrams showing the structure of the pelvic region in *Camarasaurus* were exhibited, with explanatory remarks, and the identity of *Camarasaurus* and *Morosaurus* announced.

Supplementary remarks by Dr. C. C. Mook regarding proportions of pelvis.

AN EARLY PLIOCENE MONODACTYLOUS HORSE

BY EDWARD L. TROXELL

(*Abstract*)

Because the modern *Equus* is so intimately associated with the human race there are few fossils more interesting than the remains of its ancestors, and its evolution is probably better known than that of any other mammal. The finding, however, of an unusually complete skeleton of *Pliohippus* has furnished an additional link in the series.

The search for fossils in the South Dakota Bad Lands this past summer resulted in the discovery of a one-toed horse, the earliest of which we have

authentic record. In its development it occupies a place half way between the true *Equus* and the earlier three-toed horses. It is distinguished from these ancestors by the absence of its lateral digits, but from the modern horse by the full length splint bones and by the complete ulna, which through its middle portion is less than an eighth of an inch in diameter. A large preorbital pit, which probably marks the location of a scent gland, appears to separate it from *Equus*, but allies it with several of the earlier types.

The associated fauna—*Mastodon, Teleoceras, Merycodus, Protohippus*, etcetera—indicate a very late Miocene or an early Pliocene age.

The individual had just come into full possession of its milk teeth, indicating that it was less than a year old. The completeness of the specimen and its various unique characters make it a very interesting contribution to science.

Discussion by Professor Osborn, Mr. Gidley, and the author.

Session of Thursday, December 30

Thursday morning, at 9.30 o'clock, the Vertebrate Section met for the completion of their program, Dr. F. B. Loomis presiding and Dr. W. K. Gregory acting as secretary.

PRELIMINARY REPORT OF THE COMMITTEE ON THE NOMENCLATURE OF THE SKULL ELEMENTS IN THE TETRAPODA

BY W. K. GREGORY

(Abstract)

The committee, consisting of Professor Williston (chairman), Doctors Case, Moodie, Watson, Broom, Gregory (secretary), had considered the nomenclature and homologies of the skull elements of the Permian reptiles and amphibians and modern mammals, and were in process of drawing up an alphabetic list of preferred names with synonyms. The principles of selection advocated by the committee were set forth and the homologies of the "alisphenoid" and other elements were discussed.

Remarks by Doctor Case and Professor Scott.

ORIGIN OF THE STERNUM IN THE REPTILES AND MAMMALS[1]

BY S. W. WILLISTON

(Abstract)

From the evidence afforded by Permian Tetrapoda, the author concludes that the sternum of reptiles and mammals had been derived from the abdominal ribs.

Discussion by Doctor Case, Doctor Gregory, and Professor Scott.

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[1] Read by F. B. Loomis in the absence of the author.

MOUNTED SKELETON OF CANIS DIRUS, WITH REMARKS ON THE METHODS OF RECONSTRUCTION OF EXTINCT ANIMALS [2]

BY W. D. MATTHEW

Remarks by Mr. Gidley and Professor Scott.

MOUNTED SKELETON OF BLASTOCERUS PAMPÆUS—A FOSSIL DEER FROM ARGENTINA [2]

BY W. D. MATTHEW

SKELETONS OF DIPLODOCUS AND APATOSAURUS IN THE CARNEGIE MUSEUM

BY W. J. HOLLAND

(*Abstract*)

By means of a lantern slide the speaker exhibited a photograph showing a skeleton of *Diplodocus* in the rock, with a skull of unquestionable association with the neck vertebra. This sets at rest all doubt as to the generic identity of the skull referred by Marsh to this genus. A larger skull of the "*Diplodocus*" type, with slender teeth, had been discovered very near an *Apatosaurus* skeleton, and its occipital condyles were found to fit well into the cotyle of the atlas of the *Apatosaurus*. The two genera, *Diplodocus* and *Apatosaurus* (*Brontosaurus*), had many structures in common and were nearly related.

Remarks by Professor Scott and Doctor Mook.

At the conclusion of the scientific program the section resolved itself into a committee of the whole to consider the future policy and action of the section. After a discussion of the subject by Messrs. Osborn, Scott, Holland, Case, Loomis, and Gregory, the chairman was empowered to appoint a committee of five to make recommendations to the section. The chair later appointed Prof. H. F. Osborn, Prof. W. B. Scott, Prof. S. W. Williston, Prof. E. C. Case, and Mr. J. W. Gidley.

SECTION OF INVERTEBRATE AND GENERAL PALEONTOLOGY

Wednesday afternoon, at 4.30, the Section of Invertebrate and General Paleontology met, with Vice-President Van Ingen in the chair. The first paper, in the absence of the author, was read by L. W. Stephenson and was illustrated with numerous lantern slides.

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[2] Read by W. K. Gregory in the absence of the author.

SUMMARY OF THE RESULTS OF INVESTIGATIONS OF THE FLORIDIAN AND BAHAMAN SHOAL-WATER CORALS

BY T. WAYLAND VAUGHAN

(*Abstract*)

The author will briefly summarize the results of eight seasons of field and laboratory work on the Floridian and Bahaman shoal-water corals. The different factors influencing their life will be considered, namely, relations to currents and waves, character of bottom, temperature, light, salinity, atmospheric exposure, and depth of water. Experiments on the reactions of corals to nutrient and non-nutrient particles and the food of corals will be described, and the results of experiments to ascertain the duration of the free-swimming larval stages and the growth rate of corals will be given. The bearing of the investigations on geologic interpretation will be indicated.

Following this paper was a stratigraphic one, illustrated with lantern slides and charts.

CORRELATION OF THE UPPER CRETACEOUS DEPOSITS OF THE ATLANTIC AND GULF COASTAL PLAIN

BY L. W. STEPHENSON

(*Abstract*)

The Upper Cretaceous sediments of the Atlantic and Gulf Coastal Plain are chiefly medium to fine-grained clays, sands, chalks, and marls ranging in origin from those laid down on low coastal plains, in estuaries, or in very shallow seas to those formed in waters for the most part less than 50 fathoms deep, though perhaps in part in waters exceeding 100 fathoms deep.

The formations into which these sediments may be grouped are related to each other not as the leaves of a book, a succession of regular layers of uniform thickness, but, viewed in a section parallel to the strike, they appear as a series of intertonguing lenses, great and small, the age relations of which can be determined only on the basis of paleontologic criteria.

In our present state of progress the fossils most usable in determining the age relations of the marine sediments are the representatives of the genus *Exogyra*, which were adapted for life in all but the very shallowest of the Upper Cretaceous marginal seas and which underwent evolutionary changes with sufficient rapidity to form faunal zones traceable through contemporaneous formations, whether they be chalks, sands, clays, or marls.

At 5.30 the Society adjourned until the following day.

At 8 o'clock the members attended the address of Professor Coleman, retiring President of the Geological Society of America, in the general assembly hall of the Medical School, and at 9.15 they participated in the smoker to the several societies, given by the Geological Society of Washington, at the Cosmos Club. Following the smoker a number of

the members concluded the day's exercises by attending the reception at the National Museum given by the Secretary of the Smithsonian Institution to all the visiting societies.

Session of Thursday, December 30

The Society met at 9.30 a. m., with Vice-President Knowlton in the chair.

REPORT OF THE AUDITING COMMITTEE

The report of the Auditing Committee was the only matter of business on hand. The committee attested to the correctness of the Treasurer's account; whereupon it was voted that their report be accepted.

The first papers in order were three forming a symposium on Mississippian rocks of Illinois and Kentucky. The first of these was illustrated by charts; 20 minutes.

MISSISSIPPIAN SECTION IN WEST-CENTRAL KENTUCKY

BY CHARLES BUTTS

(*Abstract*)

The Mississippian section of west-central Kentucky from the bottom upward includes the following formations: New Providence shale, 150 feet thick, overlying the New Albany (black) shale; the Kenwood sandstone (new), generally shale, with thin sandstone layers, 40 feet thick; the Rosewood shale (new), 190 feet thick, and the Holtsclaw sandstone (new), 20 to 30 feet thick. These four formations are subdivisions of the Osage group, which corresponds to the Knobstone group. The new Providence shale yields the crinoid forms of Buttonmould knob, of Burlington age, and the Holtsclaw sandstone carries the *Orthotetes keokuk* and *Syringothyris typa*, of Keokuk age. As shown in a well in Stephensport, the whole Osage group changes to limestone in the distance of about 20 miles from its eastern outcrop. The Osage group is succeeded by the Warsaw limestone, 80 feet thick, made up of shale, argillaceous or siliceous limestone and shale and highly geodiferous. The Warsaw is the same as the Harrodsburg limestone of Indiana. Above the Warsaw is the Spergen (Salem, Bedford) limestone, coarsely crystalline gray limestone, 20 feet thick. The Spergen is followed by the Saint Louis limestone, bluish gray and drab, clearly geodiferous to the east, 500 feet thick.

Above the Saint Louis is the Sainte Genevieve limestone, mainly thick bedded, light gray, largely highly oolitic, 160 feet thick. This limestone is of high purity and the quarry rock of the region.

At the top of the Sainte Genevieve is a hiatus of considerable magnitude, in which the Aux Vases sandstone of the Mississippi Valley is absent. Above the hiatus is about 30 to 40 feet of limestone, with Talarocrinus common. This limestone is succeeded by a sandstone 30 to 40 feet thick; this in turn by 40

feet of shale and limestone, above which is the "Big Clifty" sandstone, 40 to 60 feet thick, which is correlated with the typical Cypress sandstone of Illinois. Above the "Big Clifty" sandstone is 40 feet of shale and limestone, which is succeeded by 20 to 40 feet of sandstone, and the latter sandstone is followed by 30 feet of limestone carrying a profuse fauna, including such characteristic forms as *Prismopora serrulata*, *Archimedes laxa*, *Pterotocrinus bifurcatus*, and *P. depressus*. Above this limestone is about 100 feet of shale and limestone extending up to the base of the "Tar Spring" sandstone. The section included between the "Big Clifty" and "Tar Spring" sandstone corresponds to the Okaw formation of Weller. The "Tar Spring" sandstone is 40 feet thick and is succeeded above by 150 feet, largely shale, but containing thin sandstone and limestone beds extending upward to the basal Pennsylvanian sandstone. This part of the section probably represents the Menard limestone, Palestine sandstone, and Clore formation of Weller in Illinois.

Following this paper, in which the general stratigraphic section was presented, was one bearing more particularly on the points in dispute; 50 minutes.

STRATIGRAPHIC AND FAUNAL SUCCESSION OF THE CHESTER GROUP IN ILLINOIS AND KENTUCKY

BY STUART WELLER

(*Abstract*)

A broad study of the Chester rocks in southern Illinois and Kentucky has shown that the entire group is divisible into four subgroups, each of which is introduced by a massive sandstone formation, which is succeeded by a limestone and shale series. The lower Chester is introduced by the Aux Vases sandstone, and it has its greatest and most complete development in the more western portion of the Illinois basin. The lower-middle Chester, with the Cypress sandstone, and the upper middle, with the Tar Spring sandstone as basal members, have their greatest development in the southeastern portion of the basin, with only their higher limestone and shale facies extending into the western part of the basin. The upper Chester, with the Palestine sandstone as a base, is about equally developed across the basin. The Sainte Genevieve limestone, which has been included in the Chester by some, is excluded from this group.

At this point there was introduced a paper on fossil and recent algæ which had been postponed from the preceding day; 20 minutes.

COMPARISON OF THE YELLOWSTONE PARK ALGÆ WITH ALGONKIAN FORMS

BY CHARLES D. WALCOTT

(*Abstract*)

The author presented the results of further investigations of American Algonkian algæ with special reference to a study of the life habits of the recent forms found in the Yellowstone National Park.

The symposium on the Mississippian controversy was then resumed by the reading of the last paper on the subject, which was illustrated by diagrams; 50 minutes.

THE CHESTER CONTROVERSY

BY E. O. ULRICH

(Abstract)

The author defended his classification of the Upper Mississippian formations, the sequence, classification, and correlation of the beds of the Chester series in Kentucky and Illinois being discussed in particular. New evidence was presented showing a more decided Chester affiliation of the fauna of the lower as with the upper Sainte Genevieve than had been previously believed.

Of many stratigraphic breaks within the Chester series the most widely recognizable, and therefore the most important, is that between the top of the "Tribune" limestone of Caldwell County, Kentucky, and the succeeding typical Cypress sandstone (Bed 1 of Ulrich's Birdsville formation or group). Beneath this break the Chester formation includes two Chester formations—the Sainte Genevieve at the base, the "Tribune" (of Caldwell County) at the top—with a widely distributed sandstone between them. This sandstone is the same as the Aux Vases sandstone of Sainte Genevieve County, Missouri. Following Engelmann and Worthen, who had identified this Lower Chester sandstone in Hardin County, Illinois, with the Cypress sandstone, Ulrich, in his work on the Kentucky-Illinois fluorspar district, adopted the latter instead of the supposedly synonymous name Aux Vases sandstone. Now, however, since Weller has shown just what the Cypress sandstone of the type section in Union County, Illinois, is, the term Cypress sandstone, as used by Ulrich in the past (11 years), should in every instance be replaced with the name Aux Vases sandstone.

The Upper Chester or Birdsville group includes three sandstones—the Cypress, Tar Spring, and Palestine—all generally recognizable in western Kentucky and southern Illinois, and above each a calcareous formation. These Birdsville divisions vary more or less from place to place, and their variations in areal distribution and lithologic character suggests considerable oscillation of the sea in which they were deposited. As a whole, the group contains more sandstone and shale than does the lower or Montesano group.

The author admitted that the Tribune limestone of the type locality in Crittenden County, Kentucky, is the same as the Menard limestone of Illinois, and hence wholly distinct from the "Tribune" limestone of the adjoining county of Caldwell. On the other hand, he insisted that the latter is a distinct formation, limited below by the top of the Aux Vases sandstone and above by the unconformable base of the Cypress sandstone. The Renault of the Illinois section he regards as representing a part of the same interval.

The time for adjournment for lunch having arrived, it was decided to postpone the discussion of the three papers relating to the Chester until the afternoon.

The general session of the Society was called to order at 2.30, Thursday afternoon, and the first paper was presented by the author; 10 minutes.

STRATIGRAPHY OF THE CANADIAN CORDILLERA

BY LANCASTER D. BURLING

(Abstract)

A nearly complete specimen of a fossil fish was found in the "Jurassic" shales outcropping on the Canadian Pacific Railway west of Banff, Alberta, and further fossil evidence was secured as to the true age of this "down-faulted block."

The Devonian was found to rest without observable unconformity on the Cambrian in the Sawback Range just west of Banff, and at the upper end of Upper Columbia Lake, and fossil evidence was secured as to the portions of the Cambrian and Devonian involved in these contacts. Between these two localities the Devonian is not present and the Cambrian is overlain by approximately 10,000 feet of Ordovician and Silurian strata.

The "Devonian" Sawback formation was studied in detail and collections were secured from a dozen or more faunal horizons, ranging from the top to the lower portion of the formation. These are all of Cambrian age.

The "Silurian" Halysites beds near Golden, British Columbia, were found to contain, in a horizon above the massive quartzite, an abundant fauna which is strikingly comparable with the Richmond of Manitoba.

The relations of the "Graptolite shales" were more closely determined by the finding of fossils in the lower portion of the "Halysites beds" above and in the upper portion of the Goodsir shales below.

Further paleontologic evidence was secured concerning the Cambro-Ordovician boundary and the age relations of the Goodsir shales and the Ottertail limestone.

Following this paper the discussion of the three papers of the morning on the Mississippian controversy was undertaken and was participated in by Messrs. Weller and Ulrich.

The following was then presented and illustrated by lantern slides; 15 minutes.

NEW SPECIES OF THE MESONACIDÆ, WITH TWENTY-NINE RUDIMENTARY SEGMENTS POSTERIOR TO THE FIFTEENTH

BY LANCASTER D. BURLING

(Abstract)

Mr. E. C. Annes, of Edmonton, Alberta, while acting as my assistant in field-work for the Geological Survey of Canada, found a new species of the Mesonacidæ in the Mahto formation of the Lower Cambrian in the Mount Robson district of Alberta.

In general form and in the discrepancy between the segments anterior to

the fifteenth, which is spine-bearing, and those posterior to it, it resembles *Pædumias*, but differs from that genus in possessing at least 29 rudimentary segments.

Five papers transferred from the program of the Geological Society of America were then presented in order. The first of these was illustrated by diagrams; 20 minutes.

COMPARISON OF EUROPEAN AND AMERICAN EARLY PALEOZOIC FORMATIONS

BY AMADEUS W. GRABAU

(*Abstract*)

A study of the Durness limestone and associated formations of northwest Scotland has convinced the author that most of this formation, generally classed as Cambric, is of Lower Ordovicic or Beekmantownian age, separated from the Lower Cambric by a disconformity which was located in the field. The Biri limestone and Sparagmite of Norway will be considered in the light of these studies and of the recent investigations of Rothpletz. The relations of the Orthoceras limestone of Sweden to American formations will be considered, and some characters of the Siluric beds of Gotland, of Delarne, and of England will be noted. Finally the Upper Siluric equivalent of the American Monroan in the Bohemian basin will be considered.

A second paper by the same speaker followed. It was also illustrated with diagrams; 20 minutes.

SUBDIVISIONS OF THE TRAVERSE GROUP OF MICHIGAN AND ITS RELATION TO OTHER MID-DEVONIC FORMATIONS

BY AMADEUS W. GRABAU

(*Abstract*)

A detailed study of the Traverse group of Michigan, extending over 15 years, has furnished the material for a subdivision of the group and for correlation with the Milwaukee, Iowa, Ohio, Ontario, and New York mid-Devonic formations.

There was then presented a paper on Eocene algæ, illustrated by many striking lantern slides; 20 minutes.

SOME FOSSIL ALGÆ FROM THE OIL-YIELDING SHALES OF THE GREEN RIVER FORMATION OF COLORADO AND UTAH

BY CHARLES A. DAVIS

(*Abstract*)

In northwestern Colorado and adjacent parts of Utah there are extensive deposits of carbonaceous shales belonging to the Green River formation of

the Eocene, which yield petroleum on distillation, in some cases giving larger yields than the famous oil shales of Scotland. A study of the microscopic structure of these shales, by means of methods developed in studying peat and fresh biological material, has developed the fact that they contain an extensive flora of very minute algæ and other cryptogamic plants. Some of these plants will be presented and discussed. (Lantern slides, 20 minutes.)

There was then presented and discussed by Messrs. Ulrich and Weller the following paper, which was illustrated by charts; 20 minutes.

FORMER EXTENSION OF THE DEVONIAN FORMATIONS IN SOUTHEASTERN MISSOURI

BY STUART WELLER

(Abstract)

The Devonian formations in Sainte Genevieve County, Missouri, are now restricted in their distribution to a narrow zone of faulting that crosses the county in a general east-west direction. It has been possible to differentiate the faulting in this zone into two periods—one late Devonian in age and the other post-Pennsylvanian. During the earlier faulting the upthrow was all on the north, and during the succeeding period of erosion and peneplanation the entire mass of the Devonian and Silurian rocks extending northward from the fault-line was removed. The later faults followed closely the direction of those of earlier date, but in general lie a mile or less to the south of them. The upthrow of the later faults is on the south, and with the succeeding erosion and peneplanation the southern extension of the Silurian and Devonian beds was cut away. The only Silurian and Devonian record, therefore, of what was originally a succession of broadly extended seas is now preserved in the narrow strip between the two lines of faults.

The final paper of the program was read by the author and was discussed by Miss O'Connell and Messrs. Van Ingen, Kindle, Ruedemann, Wilson, and Ulrich; 20 minutes.

BOTTOM CONTROL OF THE COMPOSITION OF MARINE FAUNAS AS ILLUSTRATED BY DREDGING IN THE BAY OF FUNDY

BY E. M. KINDLE

(Abstract)

The results of collecting and dredging marine shells from the inter-tidal and shallow-water zones at 10 stations on the west coast of Nova Scotia are presented in tabular form, each of 51 species of gasteropods and pelecypods being checked in columns representing different stations and types of bottom. It is shown that a very small proportion of the species are common to types of bottom which, like black mud and gravel, exhibit sharp physical contrasts. Types of bottom, however, which are similar or closely allied in physical features have a very large percentage of species in common.

The author concludes from these observations on the influence of the character of the bottom on living faunas that the paleontologist should, instead of expecting the same type of fauna in synchronous deposits of widely unlike lithology, look for faunal contrasts in which the faunal facies varies as widely as the lithologic facies.

Register of the Washington Meeting, 1915

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CORRESPONDENT DECEASED

E. KOKEN, died November 24, 1912.

MEMBERS DECEASED

SAMUEL CALVIN, died April 17, 1911.
ORVILLE A. DERBY, died November 27, 1915.
WILLIAM M. FONTAINE, died April 30, 1913.
THEODORE M. GILL, died September 25, 1914.
ROBERT H. GORDON, died May 10, 1910.
J. C. HAWVER, died May 15, 1914.

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Minutes of the Sixth Annual Meeting of the Pacific Coast Section of the Paleontological Society

By E. L. Packard, *Secretary*

The sixth annual meeting of the Pacific Coast Section of the Paleontological Society was held in Bacon Hall, University of California, Berkeley, on Saturday, February 27, 1915, Dr. Roy E. Dickerson presiding.

Resolution of Condolence on the Death of J. C. Hawver

In appreciation of the life and scientific work of Dr. J. C. Hawver, who died on May 15, 1914, Dr. J. C. Merriam moved that the following resolutions be adopted and incorporated in the minutes of the Society, and that a copy of the same be sent to the widow of the late Doctor Hawver:

Dr. J. C. Hawver will long be remembered as a man of wide and sympathetic interests, whose ardent enthusiasm as a collector has materially aided in the study of the past and present fauna of the Sierra region. As the discoverer and explorer of Hawver Cave, in Eldorado County, California, he secured a rich representation of the Pleistocene fauna, which he has generously presented to the University of California. Though Doctor Hawver was not a large contributor to scientific literature, his name must always have a place in the history of paleontologic and geologic work in California.

General Business

A motion of Dr. J. C. Merriam was carried to the effect that the Pacific Coast Section of the Paleontological Society issue a program of the meeting of the Paleontological Society to be held in San Francisco in August, 1915, and a guide book of the excursions in a twenty-page pamphlet, and that a copy be sent to each member of the Paleontological Society.

Mr. Chester Stock reported on the cost of publishing such a pamphlet and the amount of funds already collected for such a purpose.

A report was given regarding the program of the meeting of the Paleontological Society in San Francisco in 1915.

It was moved and carried to hold the next annual meeting of the Pacific Coast Section of the Paleontological Society at Stanford University in the early spring of 1916.

ELECTION OF OFFICERS

The following officers were elected for the ensuing year:

President, John C. Merriam.
Vice-President, Ralph Arnold.
Secretary-Treasurer, Chester Stock.

The presentation of papers was then taken up.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AND DISCUSSIONS THEREON

SYSTEMATIC POSITION OF SEVERAL AMERICAN TERTIARY LAGOMORPHS

BY LEE R. DICE

(Abstract)

A study of the teeth of a number of lagomorphs from the American Tertiary has shown that these forms can not be included in the genus *Lepus*. Three new genera are therefore proposed for the fossil forms. The paper presents also a brief discussion of the phylogeny of this group.

Discussion

Dr. J. C. Merriam stated that rabbits were commonly found in the Tertiary formations of the West. The forms from the John Day Oligocene had been referred to the genus *Lepus*, but that the characters recognized by Mr. Dice warranted the separation of these forms from the genus *Lepus* and the defining of a new genus.

PLEISTOCENE MAMMAL FAUNA OF HAWVER CAVE, A FISSURE DEPOSIT NEAR AUBURN, CALIFORNIA

BY CHESTER STOCK

(Abstract)

A survey of all results of work on the Hawver Cave fauna.

Discussion

The discussion following the reading of this paper led to the conclusion that the region of Hawver Cave during the Pleistocene was a plateau quite deeply dissected by the American River. Thus it was not surprising to find a form like *Mylodon*, which appears to have been ill adapted to the rough country.

FAUNA OF THE RODEO PLEISTOCENE

BY JOHN C. MERRIAM, CHESTER STOCK, AND C. L. MOODY

(Abstract)

For many years vertebrate and invertebrate material has been collected from the Pleistocene beds exposed along San Pablo Bay and Suisun Bay. The fauna

known at the present time includes a number of forms not previously recognized. A complete list of the known vertebrate and invertebrate species is presented with tentative conclusions as to the age of these beds.

NEW MIOCENE MAMMALIAN FAUNA FROM THE TEHACHAPI REGION

BY JOHN P. BUWALDA

(*Abstract*)

The paper is a discussion of a new mammalian fauna of Middle or Lower Miocene age, obtained from strata in the summit region of the southern Sierras, near Tehachapi. The determinable material in the collections thus far obtained represents a small camel and one or more new forms of horses of the *Merychippus* type, which seem to be of a more primitive stage of evolution than any species within the genus *Merychippus* heretofore known in America.

The strata containing the mammalian remains have been cut by the faulting of the southern Sierras; the age of the fauna sets a lower limit for the date of at least the major part of this displacement.

Discussion

Dr. J. C. Merriam emphasized the importance of the discovery of this type of a tooth which so closely fulfills the prediction of Mr. Gidley regarding a form of a horse which would bridge the gap between the anchitherine and the protohippine groups.

THE BISON OF RANCHO LA BREA

BY ASA C. CHANDLER

(*Abstract*)

In *Bison antiquus* individual variation occurs in size and relative measurements of the skull to the extent of about 20 per cent, while the sex differences of these characters are small, being apparently less in *B. antiquus* than in *B. bison* or *B. bonasus*. The horn cores show approximately similar individual variations within a sex, but the average length in females is about 25 per cent less, while the basal circumference is about 33 per cent less than in males, there being no individual overlap in either case. The variation in general form, curvature, and angle of insertion of the horn cores is slight, and these are, therefore, reliable specific characters. The teeth of *B. antiquus* generally have the enamel walls of the lakes more complicated than those of *B. bison*.

STRUCTURE OF THE POSTERIOR FOOT IN THE MYLODONT SLOTHS OF RANCHO LA BREA

BY CHESTER STOCK

RECENT STUDIES ON SKULL STRUCTURE OF THALATTOSAURUS

BY JOHN C. MERRIAM AND CHARLES L. CAMP

(*Abstract*)

The peculiar marine reptile *Thallattosaurus* from the Upper Triassic of northern California has been known by very limited materials. A recently exposed skull illustrates several points of structure better than the type specimen. Fragments representing the rostral region indicate the necessity of a small modification in the first reconstruction.

REVIEW OF THE PLEISTOCENE SPECIES, PAVO CALIFORNICUS

BY LOYE HOMES MILLER

(*Abstract*)

Presence of additional material, both of the fossil form and of the nearer related living species, makes review of the entire question of relationship proper. The Yucatan turkey, *Agriocharis*, has been distinguished generically from the northern form, *Meleagris*. The Central American bird shows certain peacock affinities in the tail feathers and in the osteology of the posterior limb. The fossil species from Rancho La Brea displays characters far removed from *Meleagris* and intermediate between *Agriocharis* and *Pavo*, but well removed from either genus. A new generic designation for the Pleistocene species becomes necessary. Chapman considers the present habitat of *Agriocharis* the focus of retraction of a larger distributional area. Admitting the possibility that a similar change has taken place in the distribution of *Pavo* on the opposite side of the Pacific Ocean, it is not surprising to meet with an intermediate form in the Pleistocene of California.

HIPPARION-LIKE HORSES OF THE PACIFIC COAST AND GREAT BASIN PROVINCES

BY JOHN C. MERRIAM

(*Abstract*)

Until recently the *Hipparion* group has been very imperfectly known from North America west of the Wasatch Range, the only described forms clearly of this type being two species reported from the later Tertiary of the John Day region of eastern Oregon. Within the past few years a number of new representatives have been discovered at widely different localities, and nine or ten species are now known. As the history and distribution of the group have unusual importance in comparative study of the American Tertiary faunas west of the Wasatch, the writer has essayed to assemble the available information relating to the forms of this genus known in the Pacific Coast and Great Basin provinces.

RELATIONSHIPS OF THE INVERTEBRATES TO THE VERTEBRATE FAUNAL ZONES OF THE PLIOCENE JACALITOS AND ETCHEGOIN FORMATIONS AT COALINGA, CALIFORNIA

BY J. O. NOMLAND

(Abstract)

The work of Professor Merriam has shown that the invertebrate and vertebrate faunal zones have a rather definite relationship in several of the Miocene and Pliocene formations near Coalinga, California. This is well shown in the Jacalitos and Etchegoin formations. Invertebrate faunal zones have been located in the type section of the Etchegoin, which are correlated with those south of Coalinga, including the Mya Zone, or uppermost Etchegoin. The vertebrate faunal zones are placed with reference to these zones.

Discussion

The vertebrate fauna, which was correlated with the Mya Zone by Mr. Nomland, appeared to Dr. J. C. Merriam to be possibly of Pleistocene age and to have been derived from terrace material instead of from the Etchegoin formation. The bones of a large, highly developed *Equus*, which is not certainly known in the Pleistocene, and of a large deer of the Elk type have never been found in America in beds older than the Pleistocene. Some of the camel bones are possibly from older. Dr. Merriam congratulated Mr. Nomland on the work done in the correlation of the vertebrate and invertebrate faunal zones of this Coalinga district.

CLIMATIC ZONES IN THE PLIOCENE OF THE PACIFIC COAST

BY J. P. SMITH

(Abstract)

The climate of the Eocene of the Pacific coast was tropical or semi-tropical even as far north as Alaska. Similar conditions prevailed during the Oligocene at least as far north as Puget Sound. During the Lower Miocene the climate was mild-temperate north to Washington, while in the Upper Miocene it was warm-temperate. During the Lower Pliocene almost sub-boreal conditions prevailed as far south as Eel River, Mendocino County, California. Middle California had a climate during this time that was much as it is today. Southern California was warm-temperate, as is attested by the character of the Fernando fauna. The climate of the Upper Pliocene appears to have been cooler than that of the Lower, as is shown by the character of the faunas from southern California.

MARINE TRIASSIC INVERTEBRATE FAUNA FROM NEW ZEALAND

BY C. T. TRECHMANN

(Abstract)

The most typical Upper Triassic section of New Zealand occurs on South Island, near Nelson and near Nugget Point. The latter section consists of

about 3,000 feet of fossiliferous slates, graywackes, and conglomerates having a nearly vertical dip. The most common fossil forms obtained from these beds include a number of cephalopods, species of *Monotis*, *Halobia*, *Mytilus problematicus*, *Gyphæa*, and *Pinna*, besides several new species. A reptile, possibly representing an Ichthyosaur, was also found. The occurrence of a *Trigonia* within the Triassic of this island of a form comparable to a Jurassic species of Europe suggests that this general region was the center of distribution of that form, and that it later migrated to Europe.

Discussion

Dr. J. P. Smith suggested that the form referred to *Monotis* might prove on further study to be a closely related form, for *Monotis* is not known to occur with Halobia in either Europe or America.

FAUNA OF THE TEJON GROUP IN THE CANTUA DISTRICT OF THE COALINGA QUADRANGLE, CALIFORNIA

BY ROY E. DICKERSON

(*Abstract*)

The Eocene strata between Domengine and Cantua creeks, Coalinga quadrangle, belongs to the Tejon group. These strata appear to be equivalent to the Eocene strata in the vicinity of Mount Diablo. They apparently represent a longer portion of Eocene time than the Tejon of the type locality.

The fauna of the lowermost beds is older than the *Rimella simplex* Zone, which is the fauna of the type Tejon. This lowermost fauna is tentatively correlated with the Turbinolia Zone of the Mount Diablo region.

The fauna of the white sandstone member is, as a whole, the equivalent of the typical Tejon, although the fauna from the uppermost beds may be transitional between the *Rimella simplex* Zone and the *Siphonalia sutterensis* Zone.

FAUNA OF THE TEJON IN THE SAN DIEGO COUNTY

BY ROY E. DICKERSON

(*Abstract*)

The Tejon-Eocene strata of San Diego County have yielded a fauna of over ninety forms, many of which are common species in the Tejon of Cañada de las Uvas. The *Rimella simplex* Zone is present in both localities. Orogenic movements in post-Eocene time have been far less vigorous in the vicinity of San Diego than in middle California.

MOLLUSCAN FAUNAS FROM DEADMANS ISLAND

BY T. S. OLDROYD

(*Abstract*)

Small areas in this locality have recently yielded a great number of species, some of which are new. A review of the collecting in this vicinity is given and the ranges of some of the species are considered.

CORALS FROM THE CRETACEOUS AND TERTIARY OF CALIFORNIA AND OREGON

BY J. O. NOMLAND

(*Abstract*)

Although a number of corals have been described from the Cretaceous and Tertiary of the Pacific coast, the members of this group have been used only to a limited extent for correlation purposes. The geologic and geographic ranges of this group are discussed on the basis of the much enlarged coral fauna now known from this coast.

EOCENE OF THE LOWER COWLITZ RIVER VALLEY, WASHINGTON

BY CHARLES E. WEAVER

Discussion

Doctor Dickenson stated that Doctor Weaver should be congratulated on this excellent piece of work, which placed the stratigraphy of the Cowlitz basin on such a firm basis.

Mr. Clarence Waring thought that the faunas from that region showed some basis for separation into horizons, and that they should not be treated as a unit.

FAUNAL STUDIES IN THE CRETACEOUS OF THE SANTA ANA MOUNTAINS OF SOUTHERN CALIFORNIA

BY EARL L. PACKARD

(*Abstract*)

The fauna from the Santa Ana Mountains is more closely related to that of the typical Chico than to that of the Horsetown. The peculiarities of this southern fauna are attributed to the difference between the environment of the Sacramento Valley and that of the Santa Ana Mountain basin of deposition.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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DRY LAND IN GEOLOGY[1]

PRESIDENTIAL ADDRESS BY ARTHUR P. COLEMAN

(*Read before the Society December 29, 1915*)

CONTENTS

INTRODUCTION

After visits to South Africa, Australia, and India to study dry-land deposits, it has become very evident to the writer that most of the earth is covered with water, and also that a ship is the most tantalizing of all modes of travel for a geologist, since captains have a prejudice against anything of geological interest, such as rocks or reefs or shoals. After 1,200 miles of sheltered voyaging behind the great Australian barrier, one may reach Java without ever seeing a coral reef at close quarters. Except the oozes dredged from the deep sea and the contours of its bottom revealed by soundings, the three-quarters of the globe beneath the ocean have scarcely any message for the geologist. That the waves and the tides do important geological work is true, but to hear the growl of the breakers and to see them pounce on their prey, one must travel in a small boat close to shore and not in an ocean liner. Even to study the action of the sea on the shore it is better to be on land. The dry shores

[1] Manuscript received by the Secretary of the Society January 27, 1916.

of Lake Bonneville, as read by a Gilbert, give more instruction in regard to wave work than all the foam and tumult of the surf on the strand.

The geologist is essentially a land animal, and yet until recently most books on geology, especially text-books, have had surprisingly little to say of the land and its conditions. The writers seemed all to belong to the blue-water school, so much of their space has been given to the sea and its inhabitants. It is true that continents were mentioned, almost apologetically, when one came to the Cenozoic mammals, but even the Glacial period did not lift geology above the sea for some of the older writers, who preferred icebergs to glaciers for the manufacture of boulder-clay.

This concentration on the sea and its life went to astonishing lengths in the more ancient parts of geological history. Like most of our older geologists, my first nourishment in the science was drawn from Dana's "Manual." Unfortunately that earliest of text-books has been lost, but curiosity led me to glance over his fourth edition (1895) to see how the dry land fares in its pages.

There is the usual fiery introduction to historical geology, dividing Archean times alliteratively into Astral, Azoic, and Archeozoic eons, with a lithic era beginning at 2,500° Fahrenheit and an oceanic era commencing when the earth had cooled to 500°, followed by eras of the earliest plants and the earliest animals as the boiling ocean cooled to endurable temperatures. When the streaming waters had permanently condensed in the hollows of the original crust, there was left a V-shaped nucleus of dry land about which the continent of North America was to be built up. After this encouraging start with a quite respectable dry-land area as a foundation, historical geology becomes submerged in seas, mostly shallow, until the end of the Silurian. Out of 114 pages devoted to this part of the world's history, the total number of lines referring to the land and its inhabitants amount to only one page, while the Devonian land plants and animals are given only 4 pages out of 46. It is true that most of the Carboniferous chapter is devoted to the rank growths of the coal swamps, but these amphibious plants have little to do with actual dry land. They never rise far above sealevel and are frequently lowered beneath it to get a fresh covering of mud or sand. The araucarias of the hills inland are barely mentioned, and it is not till one gets well on into the Mesozoic that the dinosaurs compel the student to depart a little from the seashore. Even then there is a suggestion that at least some of the clumsy beasts preferred splashing along the mud flats or paddling in the lagoons. There is no hint of lean creatures hastening with long strides to the shrinking water-holes of a semi-arid region.

Another stand-by of student days, this time in Germany, was Credner's "Geologie," which up to the end of the Devonian gives 2 pages out of 58

to the land and its dwellers. Only 32½ pages out of 300, up to the beginning of the Quaternary, have to do with terrestrial things, even the dinosaurs almost escaping notice. The dry land was evidently of small importance.

It is not unnatural that in the beginning geology should devote itself mainly to things marine, for the favored haunts of men are almost all founded on stratified rocks. Werner's idea of a world deposited layer by layer from a primeval sea seemed reasonable when he lectured in Freiberg, though the Bergakademie stands on eruptive gneiss; and when William Smith began stratigraphic geology, on an island where one can never get many miles from the sound of the surf, he had to collect seashells from the rocks as coins with which to date the formations.

The regular succession of marine faunas in the stratified rocks laid the foundation for our chronology, showed the orderly development of living beings, and made possible the correlation of the rocks of different countries. The study of marine fossils was necessary to the building up of historical geology on a sound basis, therefore, so that the almost exclusive attention given to the seas and their life was not unjustified. In those earlier days continents had a place in geology mainly as limiting the migrations of marine faunas or as providing sediments for the shallow seas. In other respects they were largely negative things, vacuums where nothing took place, since they provided no fossil-bearing beds, while the waters around them were swarming with life and activity.

It seemed quite the correct thing thirty-five years ago, when the older men among us were students, to spend most of our time bending over rows of brachiopods in museum cases and memorizing lists of type fossils, so as to fix the age of rocks we might encounter in our field work. In those days the wash of the waves and the smell of the seashore seemed to permeate geology, and dry land was seldom mentioned or thought of by professors or students. Most of geology consisted of stratigraphy and invertebrate paleontology. Bluff old Credner had some justification for devoting nine-tenths of his historical geology to a consideration of the doings of the sea and its inhabitants. The land had scarcely been discovered. Even the "Age of Mammals" was named and subdivided in accordance with the proportions of extinct to living shell-fish and not from the rapid evolution of the mammals and their differentiation into the highest forms of animals the world has known.

Discovery of the Land

It can not be said that the early geologists entirely ignored the land. An unmistakable land surface, like the "dirt bed" of the English Pur-

beck, with its araucarian stumps still rooted in the soil, was occasionally recognized, though such occurrences are almost unknown in formations older than the Carboniferous. It was recognized, also, that heat and drought best accounted for the beds of gypsum and rock-salt found in several of the more ancient formations, though the materials might have come from the evaporation of inclosed arms of the sea, and so might not be really continental deposits.

The most typical land deposits, those of arid and of glacial climates, were seldom recognized as such and were generally included among the marine stratified rocks, though the absence of fossils was disquieting. Even the red sandstones, with their hot, desert colors, were often looked on as marine, or else possibly as formed in great lakes, because they contained no marine fossils. The ancient boulder-clays were merely coarse, water-formed deposits of some peculiar kind.

In most cases, however, dry-land periods are not represented by deposits of any sort, but by the gaps in the sequence of formations, for normal land conditions mean erosion and denudation. Their only record is usually a discordance, and a dry-land interval shown only by an unconformity naturally passed almost unnoticed. Most of the chapters of the world's history are written under water and show a strong bias toward the side of the water animals.

The only continental deposits beside those of arid and glacial conditions which have a good chance of being preserved and recognized are those of the coal swamps, and they persist mainly because they are on debatable ground often invaded by the sea. During much the greater part of the world's history happenings on the land are recorded only in the most accidental way, as by some stray leaf or tree trunk or carcass drifting down a river to be buried in the mud at its mouth. It is seldom that land formations can be found on a broad enough scale to reconstruct continental surfaces and conditions.

Though it is certain that lands and their inhabitants have existed in unbroken succession from early times, the lands themselves are in geology mostly shadowy things. Whether they were mountainous or flat we can only infer from the kind of sediments they sent down to the sea.

During most of the world's history the climate seems to have been mild and moist, even to the poles, and deserts and ice-sheets were apparently absent. We are living in an exceptional time characterized by extremes of climate and are apt to think of such extremes as normal. When Miocene plane trees grew luxuriantly on Spitzbergen, in latitude 78°, the whole circulatory system of air and water must have been different from the one we are accustomed to. Extremes of cold and perhaps also of dry-

ness must have been largely absent. There could have been no cold ocean currents flowing beside warm lands to desiccate the winds blowing over them, as in southern California and northern Chile, at the present time. The most characteristic land deposits, those of deserts and ice-sheets, belong especially to the short periods of stress and trouble separating the long, genial, but unenterprising, geological ages, and hence must be relatively rare in the column of formations.

These comparatively unusual types of deposits began to attract attention about sixty years ago in Europe, and geologists of the Indian Survey correctly interpreted the ancient Talchir boulder-clays in 1859. With deserts before their eyes for comparison, they recognized also ancient arid deposits. In America not much attention was given to continental formations till Davis and his brilliant physiographic school, twenty-five years ago, began to explain the Cenozoic beds of the west as dry-land deposits. At about the same time Walther and other Germans took up the careful study of desert processes, giving the clue to the origin of ancient red sandstones and their accompaniments. Of late years most of us have paid at least brief visits to deserts and have felt the charm of their bareness, their loneliness, their clear, cool, night skies and hot orange haze at noon, and have watched the dusty pillars of the "go-devils" transport a train-load of dust across the Kalihari, or have seen the low dance of the yellow sand grains as a hot wind builds up a barchan in Nubia. We have seen the selective carving of the desert sand-blast on rocks of unequal hardness, have wondered at the brown desert varnish on exposed rock surfaces, and have speculated as to the origin of "calcrete" or "kankar."

Geologists are now on the alert for continental, and especially desert, formations, and there are few red sandstones which have not been picked out of the marine ragbag and set aside as belonging to the land. It is even possible that the pendulum has in some cases swung too far and will have to swing back again. Some of the red sandstones or shales handed over to the desert may yet disclose marine fossils and have to return to the seashore.

A glance through recent text-books of geology in English, French, and German shows how widely attention has been given of late years to continental, and especially desert, formations. Arid conditions have been recognized, or at least suspected, in nearly all the main subdivisions of historical geology. They have been mentioned by one author or another in the Pleistocene, the Pliocene, the Miocene, the Eocene; the Cretaceous and the Triassic; the Permian, the Carboniferous, the Devonian, the Silurian, and the Cambrian; the Keweenawan, and possibly one or two earlier of the Precambrian series. In fact, only the Jurassic and the

Ordovician seem to have escaped the drought, and it may be that a more careful search through the literature would disclose deserts there also.

A number of the suggestions noted are only tentative, however, and wide-spread and unmistakable desert formations seem confined to the Pleistocene, Triassic, Permian, Devonian, and late Precambrian. Of these the Pleistocene deserts may be looked on as continuing to the present, the Triassic deserts form an aftermath of the arid conditions of the Permian, and the Devonian deserts seem less extensive than the others. The three times of greatest aridity appear to be, 1, the Pleistocene continuing to the present; 2, the Permian-Triassic; 3, the late Precambrian.

Though well known, it may not be amiss to recall some features of these three periods of widely extended desert conditions.

Arid Zones of the Pleistocene and Present

The map of the world shows two zones which are largely desert, one in each hemisphere, with a broad zone of heavy equatorial rainfall between. To the north of the northern desert belt there are moister conditions, and the same is true to the south of the southern one. There is reason to believe that Antarctica is arid, evaporation exceeding precipitation, and the same may be true of some Arctic lands. The precipitation on Spitzbergen is stated to be only 6 inches per annum.

The two belts of deserts do not run quite parallel to the equator. The northern one, beginning with the Sahara and Nubian deserts, in Africa, runs northeastward through the Arabian and Indian deserts to those of central Asia, where the desert of Gobi reaches nearly 50° of north latitude. In North America desert conditions are less extensive and do not extend beyond latitude 40° or 45°.

In the southern hemisphere the bodies of land are much smaller, and the deserts of South Africa, Australia, and South America are correspondingly small as compared with those north of the equator. Their southern limits are, roughly, 30°, 40°, and 45° south latitude.

Penck has shown, I think satisfactorily, that these desert belts migrate toward the equator in cold periods, narrowing the zone of tropic rains, and move respectively north and south in warmer periods. In the mildest geological periods it would almost seem as if the equatorial belt of warmth and moisture expanded to cover the whole earth, abolishing both deserts and ice-sheets, and these appear to be the normal conditions when peneplanation has advanced far and shallow seas transgress widely over the continents.[2]

[2] Die Formen der Landoberfläche u. Verschiebungen der Klimagürtel, Koenigliche, Preus. Ak., vol. iv, 1913.

Arid Period of the Permian and Triassic

Going back to Permian and Triassic times, much of the evidence has been buried or destroyed; yet it is certain that deserts extended widely in many lands. Red sandstones, arkoses, and shales with mud cracks and footprints, beds of salt and gypsum, are reported from England, Germany, Austria, and Russia in regions now well watered. In North America there were the wide-spread red beds of the Rocky Mountain region and the band of desert sandstones extending from Prince Edward Island southwest to Virginia; so that arid conditions covered far more of Europe and North America than now. In India the Gondwana system includes great thicknesses of coarse sandstone with bands of conglomerate, supposed to be of fluviatile origin, terrestrial deposits, but perhaps not of a specially arid kind;[3] but no other references to Asiatic land conditions have been found. I. C. White reports a thick series of massive red and gray sandstones, probably of Triassic age, resting on Glossopteris beds with coal seams in Brazil, but expresses no opinion as to the climate during the deposition of these upper beds. The basal conglomerate under the coal he thinks glacial.[4] Red beds of sandstone and conglomerate to the thickness of 1,600 feet occur, according to Rogers, in the Karroo system of South Africa, but he puts them probably above the Triassic.[5] Whether the 1,100 feet of Hawkesbury sandstones of the Triassic in New South Wales, with their steep cross-bedding, bands of conglomerates, worm tracks and sun cracks, imply an arid period in Australia is perhaps uncertain, though they are undoubtedly continental deposits.[6]

It will be seen that land formations, often of a very arid kind, are found in most of the continents in Permian or Triassic times. They seem to occur rather later in the regions which endured the cold of the Permocarboniferous glaciation than in Europe and in our Western States, but the correlation is not very certain. These "New Red" deserts following on the heels of the severest ice age on record close the Paleozoic calamitously. It is not surprising that such extreme climatic changes put an end to the lush growths of the coal swamps, so that only hardy plants survived, and hastened the departure of the semi-aquatic amphibia, while giving an impetus to the development of the reptiles as dry-land inhabitants.

There must have been very dry conditions during the Upper Silurian (Salina) of America, as shown by the salt and gypsum beds of New

[3] Oldham: Geology of India, 2d edition, pp. 150-151.
[4] Brazilian coal fields, p. 31.
[5] Geology of Cape Colony, p. 216.
[6] Geology of New South Wales, Suessmilch, pp. 158-160.

York, Ohio, Ontario, and Manitoba; and the succeeding Old Red beds of Scotland and other European countries suggest a similar climate, but I have not found evidence of arid conditions on a wide enough scale to make it desirable to discuss them here.

Late Precambrian Deserts

Desert characters have been ascribed to sandstones, perhaps belonging to the earliest Cambrian, but more probably the uppermost Precambrian, in many parts of the world. They include apparently the Keweenawan and part of the Belt series in America, the Torridonian of Scotland, part of the Gaisa beds of Norway, perhaps also the Sparagmite of Sweden and the Jotnian of Finland. Whether the Matsap beds of Cape Colony and some of the Kuddapah sandstones of India, described as shore deposits, or the Vindhian sandstones and conglomerates should be included is uncertain.

If these are all of the same age and have been correctly interpreted as arid deposits, this was the most severe and extensive period of desert conditions known. In many places on the Canadian Shield the coarse red sandstones, usually with some conglomerate at the base, may be seen resting on an Archean surface of granitoid gneiss or Keewatin schist or Animikie slate, the original land surface of gently rounded hills and shallow valleys belonging to an ancient peneplain. In some outcrops the crumbling gneiss beneath, an old regolith, provides most of the materials for the basal conglomerate. This is true at various points on the north shore of Lake Superior and apparently also in Scotland, where the Torridonian rests on the Lewisian. The Lake Superior Keweenawan, though much the best known, is on a small scale as compared with the areas of sandstone of the same age farther north in Canada. The Athabasca sandstones of Tyrrell, those of Great Bear Lake and of central Labrador, not to speak of smaller areas, indicate a very broad surface exposed to arid conditions in North America. These red sandstones still occupy not less than 50,000 square miles, and it is certain that much greater areas of such relatively soft and easily attacked rocks have been destroyed in the long dry-land periods of later times.

It appears that in this desert period the arid districts were mainly in the northern hemisphere and to the north of latitude 48°—that is, very much farther north than the belt of deserts of the present northern hemisphere. It is unknown, of course, to what extent Keweenawan rocks are buried to the south of Lake Superior or of Scotland. The breadth of the belt as known in North America is at least 20°, since rocks of this age reach nearly to 70° north latitude in the region north of Great Bear

Lake. The Gaisa beds on Varanger Fjord, in Norway, reach the same latitude, and the Scotch Torridonian about latitude 58°.

It is hard to imagine red soils, drifting sands, and the hot winds of deserts as existing in regions now tundra-covered and frigid; but this seems to have been true in the more northern areas.

Glacial Periods

Thus far arid conditions only have been mentioned, but the best preserved land surfaces of the past are those sealed up unchangeably beneath glacial deposits. It seems absurd to couple together deserts and glaciers, so opposite to one another in every respect; nevertheless in running down the column of historical geology one finds these contradictory phenomena closely linked together. In almost all the periods where aridity has been proved there have been found also proofs of ice-action, the two seemingly hostile conditions occurring either at the same time in different parts of the world or one after the other in the same region. We live in the closing stages of a great Glacial period, extensive ice-sheets still surviving in Greenland and the Arctic islands, as well as in Antarctica, and yet wide deserts are found in all continents save Europe.

More or less certain evidence of ice-action has been found in the Pleistocene, the Eocene, the Cretaceous, the Triassic, the Permian, or Permocarboniferous, the Carboniferous, the Devonian, or possibly Upper Silurian, perhaps the Cambrian, certainly the late Precambrian, and the Lower Huronian. The list just given is closely parallel to that given for the arid periods.

Only four of these glacial times are of prime importance—those of the Pleistocene, the Permocarboniferous, the late Precambrian, and the Lower Huronian.

Pleistocene Ice Age

The Pleistocene ice age, from which the world is just emerging, unless this happens to be an interglacial period, is so familiar that little need be said of it. Boulder-clay, moraines, and deposits formed by glacial waters occur over 6,000,000 square miles of the northern hemisphere; smaller areas are found in the southern hemisphere, and Pleistocene moraines reach thousands of feet below the present glaciers on high mountains all over the world, even under the equator, showing that the climates of the whole world were affected. Beneath the glacial deposits in many places there are characteristically smoothed and striated rock surfaces, though near the edges of the ancient ice-sheets there are thousands of square miles where loose materials were not swept away to bedrock.

The central areas were most effectively scoured, and in many places the rocks beneath, owing to unequal hardness, have been shaped into *roches moutonnées,* forming hills well rounded on the side from which the ice advanced. Boulder-clay is a highly specialized product of land ice; floating ice, such as floes or bergs, is not known to produce it, the materials dropped through the water when melting being necessarily more or less stratified. The "soled boulders" or "striated stones" from boulder-clay have special characters not caused by any other agency, such as mudflows or torrential action. They are manufactured articles, easily recognized by one familiar with glacier work, and not to be confounded with stones scratched or smoothed in other ways. These familiar features are recalled because they serve as criteria for the recognition of the ancient glaciations to be mentioned later.

The hummocky, *moutonnées* surfaces left by the Pleistocene glaciers on Archean rocks which have disordered structures and vary in durability are very characteristic and were once looked on as the direct handiwork of the ice-sheets themselves. The clean and polished surfaces of fresh rock, generally well striated and often deeply scored, are eloquent of the stripping and grinding of the glacier, but the original surface forms have not been greatly changed, as will be shown later.

Most of the great Pleistocene ice-sheets gathered on comparatively low ground and reached sealevel, often occupying large areas of shallow sea-bottom as well as the land. Few of them began in mountain regions, and the flow of those on level ground was caused by the slope of the upper surface of the ice-mass and not by the inclination of the floor beneath. They could even move uphill for thousands of feet, when the ice-sheet was thick enough in the center, and their flow took place outward in all directions.

Doubtless conditions were similar in earlier glaciations, and it is not necessary to assume great mountain ranges to account for them, as some geologists have done.

Permocarboniferous Ice Age

The first undoubted proofs of ancient glaciation seem to have been found by the Blandfords in India, and the first Memoir of the Indian Survey (1859) contains a brief account of the Talchir tillite in central India, illustrated by a rough sketch. Soon after South African and Australian tillites of the same age were described. There was at first a good deal of skepticism expressed by European and American geologists as to the reality of the discoveries. Ramsay's interpretation of certain English boulder conglomerates as glacial a few years before had been disputed,

which cast doubt on the new reports from the far east and south. Was not the Carboniferous a tropical time, even in the Arctic regions! Glaciers and the steamy coal swamps did not mix well together.

Since then, however, many northern geologists, including expert glacialists, have studied these marvelous deposits, and for a number of years no one has doubted their glacial origin, in spite of the fact that most of the localities are in what are now warm temperate or even tropical regions. All the evidences for the ice-action on a large scale found in our Pleistocene are repeated, with the difference that the Pleistocene till ceases about 38° from the equator, while the Talchir tillite in India reaches well within the tropics (18° north) and Permocarboniferous tillite in West Australia touches the tropics. In South Africa the Dwyka tillite reaches 24° 30′, or even 22°,[7] and I. C. White and Woodworth report similar tillites between 25° and 30° in southern Brazil.[8] New localities have been reported within the last few years in Argentina[9] and the Falkland islands;[10] but only few and unimportant occurrences are known in the northern hemisphere outside of India. They have been reported from Herat in Afghanistan, Armenia, and the Urals; and in western Europe they have been described from central France[11] and the Frankenwald.[12] In North America tillites, probably of the same age, have been found by Sayles near Boston[13] and by Cairnes on the Alaskan boundary.[14]

A year ago, near Penganga River, under the hot sun of India, in latitude 19° or 20°, I walked across fields of ancient till strewn with glaciated stones and boulders, and stood on a well polished and striated surface of Vindhian limestone, as typical as can be found in Ontario or northern New York. This resurrection of an ice-worked surface of the Paleozoic, in what are now the sweltering tropics, gives a glacial geologist something to ponder over; and to see the same things in Africa and Australia, only on a much larger scale, as I have had occasion to do within the last few years, raises some of the most thrilling problems in all geology.

[7] For literature see Glacial periods and their bearing on geological theories, by the writer. Bull. Geol. Soc. Am., vol. 19, pp. 347-366; and Schuchert: Climates of geologic time. Carnegie Inst., Pub. No. 192, pp. 263-298.

[8] Brazilian coal fields, pp. 11-15; and geological expedition to Brazil and Chile. Bull. Mus. Comp. Zool., Harvard, vol. lvi, No. 1.

[9] Keidel: Compte Rendu, Geol. Congress, XII Session, 1914, p. 676.

[10] Halle: Geol. Mag., n. s., Dec. 5, vol. v, pp. 264-265.

[11] Compte Rendu, 1895, vol. cxvii, p. 255. Striated stones and angular blocks up to 12 or 15 cubic meters are described.

[12] J. D. G. G., 1893, vol. xlv, p. 69. Boulders occur scattered through unstratified graywacke in the upper Culm.

[13] Sayles and La Forge: Science, n. s., vol. 32, pp. 723-724; also Harvard Bull. Mus. Comp. Zool., vol. lvi, No. 2.

[14] G. S. C., Mem. 67, Alaska Boundary Survey, pp. 91-92.

Our Pleistocene ice age, with its array of glacial and interglacial beds, was merely an imitation on a much smaller and less impressive scale of the tremendous Paleozoic ice age, which laid down in places 1,000 feet or more of till and included interglacial times long enough to form great coal seams, as in the Greta beds of New South Wales.

These ancient boulder-clays and *moutonnées* rock surfaces of the southern continents bring us face to face with the most dramatic moment in geology, when a world enervated by the moist, hot-house conditions of the earlier Carboniferous found itself in the grip of the fiercest and longest winter of the ages, followed by the merciless droughts of the Permian and Triassic.

Late Precambrian Ice Age

Still more ancient tillites have been found in a number of regions, sometimes described as Lower Cambrian; at others as uppermost Precambrian. In a few cases Cambrian fossils have been collected in beds above the tillite, but, so far as I am aware, never beneath it. It is possible that there were two early ice ages, with an interval between; but it seems more probable that they are of the same age and all really Precambrian. The Australians believe that their more ancient tillites are Cambrian, however.

Tillites have been suggested at two places in the Keweenawan of America. They occur in the Gaisa beds of Norway, where there is a striated surface beneath; perhaps also in the Torridonian of Scotland. In Australia Howchin describes an area of 460 miles by 250, and they are found also in Tasmania. They are reported from the Nant'ou formation in China; the Griquatown series in Cape Colony, where they have an area of at least 1,000 square miles, and near Simla, in India. The last two mentioned may be older than the Keweenawan. Sir Thomas Holland thinks the Simla tillite may even be as old as the Huronian.

These tillites belong to higher latitudes than those of the Permocarboniferous, none coming nearer the equator than 29°; but some of them occupy regions now warm temperate, while the ice-sheets of the Pleistocene halted at about 38° in North and South America and 52° in Europe. In so old a period one can hardly expect to find very complete evidence of the area covered by glaciers; but this ice age seems to have been more severe than that of the Pleistocene.

Huronian Ice Age

Much farther off in the abyss of Precambrian time is the Lower Huronian Glacial period, thus far known with certainty only from the Cana-

dian Shield, unless the tillite reported by Hintze from the Wasatch Mountains and that from Simla in India are to be referred to so early an age. A characteristic tillite with well striated stones has been found in the famous Cobalt region, its hard boulder-clay cut by the richest veins of native silver in the world. Striated stones have been found also 60 miles to the east, in the Province of Quebec, by members of Morley Wilson's geological survey party,[15] and one from the original Huronian region, 160 miles to the southwest, has been figured by Collins.[16] Areas of similar coarse boulder conglomerate or tillite, sometimes inclosing blocks tons in weight and miles from their source, have been mapped at various points as far northeast as Chibougamau, 320 miles from Cobalt, and have been found also to the west of Cobalt. They are widely scattered over the Canadian Shield and were once much more extensive, covering no doubt many thousands of square miles.

In most places the tillite rests with gentle dips on the low hills and shallow valleys of a peneplain closely resembling the present Laurentian peneplain. In some places the tillite passes downward, with no visible break, into an old regolith due to the decay of the Laurentian gneiss or Keewatin greenstone beneath. In others the rock below has been smoothed and polished, though no striæ have yet been found on it.

It is impressive to come on this old land surface half way down in the Precambrian succession, yet as thoroughly baseleveled as the neighboring undulating surface of gneiss and greenstone from which rain and frost are now stripping the boulder-clay. The continent sealed up beneath the Huronian tillite looks as finished and as ancient as the Laurentian peneplain beneath the boulder-clay of the last ice age. The strenuous history of the world since Huronian days could add nothing appreciable to its hoary antiquity. Great mountain ranges had already been gnawed down to the bare crystalline foundations before the ice of the Huronian covered the surface with boulder-clay, and this all happened long before a trilobite was entombed in the mud of a Cambrian sea.

Though the extent of the Huronian ice-sheet is only imperfectly known, it is certain that a plain in all respects like that beneath the tillite stretches 2,000 miles northwestward to the Arctic Ocean and more than 1,000 miles northeastward to the edge of Labrador; for flat-lying areas of Animikie or Keweenawan rocks cover a dozen broad areas of similar peneplain in other parts of the Canadian Shield. The same plain slips gently under Silurian and Devonian sediments in the central depression of Hudson Bay, under Ordovician limestone and Potsdam sand-

[15] G. S. C., Mem. 39, pp. 88-97.
[16] G. S. C., Museum Bull., No. 8, plate i.

stone in Ontario, and under Silurian, Devonian, and Cretaceous rocks toward the southwest. How far the unchanged pre-Huronian peneplain or its little changed successor extends southwestward beneath the stratified rocks is unknown.

Much of this vast surface has been buried at one time or another and sheltered from erosion by marine sediments, and has since been disinterred scarcely modified; but it is probable that it was never all covered by the sea at once. Portions of it seem to have remained dry land as cities of refuge for the inhabitants in every inundation.

That other continental nuclei have had similar histories may be considered certain. In Scotland and Scandinavia nearly horizontal Precambrian beds, whether of glacial origin or not, cover a peneplain closely like ours; and quartzites and conglomerates called Precambrian may be seen resting with gentle dips on a similarly truncated plain in West Australia. Near Clackline, for instance, Huronian-looking quartzite rests on gneiss penetrated by pegmatite dikes; and at several places in the neighborhood of Kalgourlie and Koolgardie a somewhat tilted conglomerate, like that of the American Huronian, overlies the steeply dipping gneissoid rocks.

Pre-Huronian Land Conditions

No unchanged land surface has yet been found below the peneplain just described, but important land areas can be inferred with certainty, though now obliterated by squeezing and folding and the metamorphism due to eruptive granites. The great development of clastic sedimentary rocks included under the names Seine Series, Sudbury Series, Temiscaming Series, etcetera, widely distributed over the Canadian Shield, imply broad lands and even mountain ranges far older than those destroyed before the Huronian.

They generally begin with a great basal conglomerate, so coarse and bouldery sometimes as to suggest ice-action, but squeezed and rolled out and folded in with other rocks in ways that make the finding of striated stones or a striated surface beneath quite hopeless. It is, however, highly probable that the climate was, in general, cool and moist, for the rocks are gray and often include arkoses with little weathered feldspars, though Lawson speaks of the Seine conglomerate in one place as a "fanglomerate" of desert formation. The rocks as a whole suggest a continental origin and their materials must have come from the weathering of land surfaces. Some of the graywackes and slates are very evenly bedded and show regular alternations of coarser and finer materials caused by varying seasons, either warm and cold or wet and dry. They resemble the stratified silt and clay laid down in glacial lakes at the end of the Pleis-

tocene. Sederholm's Bothnian slates with seasonal banding, probably of somewhat the same age, show similar conditions in Finland.

Land can be discovered still farther down in the misty depths of time, for the pebbles of the Seine and Doré conglomerates include far older sedimentary rocks derived from the Keewatin or Couchiching or Grenville Series, showing vast destruction of land surfaces in pre-Laurentian ages at the very beginning of the geological record.

These glimpes of American land surfaces in a past twice removed from the ancient pre-Huronian continent give one a strange vista into a dim antiquity almost infinitely remote from a dweller in the post-Pleistocene. There is no visible beginning to dry land on the continent of America.

Why should there be Dry Land?

Though it is commonly accepted that there were lands in the earliest known times, there are geologists who hold a theory of the origin of the world which logically excludes the possibility of land showing itself above the sea. The original nebular hypothesis, if followed without mishap from the stage of a cooling gas to that of a liquid, and then of a solid, would result in a correct spheroid of rotation. The lithosphere thus formed would be covered by an unbroken hydrosphere, followed in its turn by an atmosphere. A good workman would certainly have come close enough to the ideal form of his world to prevent errors amounting to 60,000 feet. A properly manufactured world, following the orthodox nebular process, would be completely covered by an ocean 8,000 or 10,000 feet deep.

This ideal world without a continent or an island would have avoided many difficulties. Land animals, blundering, bloodthirsty, even cannibal in their crude instincts, could never have existed. The ocean itself might never have been inhabited if life originated, as is commonly supposed, under shallow-water conditions. How quiet and peaceable such a world would have been! One almost longs for it under the turmoil of present conditions.

A world without land would have had its disadvantages, however. There could have been no geologists and no geology.

But it is idle to speculate as to the possibilities of a landless world. The blunder was committed and the lithosphere was so far warped out of shape that more than a quarter of it rises above the sea. One might inquire, however, whether the blunder might not have been rectified by providing more water, so as to drown out the objectionable lands. We know that there have been times when much of the present continental area was encroached on by the sea. Was there more water then, or was it merely

differently arranged? Large amounts of water are withdrawn from circulation by the hydration of various minerals. Are they balanced by the amounts restored as juvenile waters and the steam from volcanoes, assuming, of course, that volcanoes give off steam and not ammonium chloride? Probably most geologists take it for granted that the amount of water on the globe is nearly constant from age to age.

The existence of dry land at all when there is so much water on the earth is a profound mystery not even plausibly explained by the nebular hypothesis, since it demands an inexcusable irregularity in the working of the nebular machinery.

Have Oceans and Continents ever changed Places?

Admitting that in the beginning the lithosphere bulged up in places, so as to form continents, and sagged in other places, so as to form ocean beds, there are interesting problems presented as to the permanence of land and seas. All will admit marginal changes affecting large areas, but these encroachments of the sea on the continents and the later retreats may be of quite a subordinate kind, not implying an interchange of deep sea-bottoms and land surfaces. The essential permanence of continents and oceans has been firmly held by many geologists, notably Dana among the older ones, and seems reasonable; but there are other geologists, especially paleontologists, as well as zoologists and botanists, who display great recklessness in rearranging land and sea. The trend of a mountain range, or the convenience of a running bird, or of a marsupial afraid to wet its feet, seems sufficient warrant for hoisting up any sea-bottom to connect continent with continent. A Gondwana Land arises in place of an Indian Ocean and sweeps across to South America, so that a spore-bearing plant can follow up an ice age; or an Atlantis ties New England to Old England to help out the migrations of a shallow-water fauna; or a "Lost Land of Agulhas" joins South Africa and India.

It is curious to find these revolutionary suggestions made at a time when geodesists are demonstrating that the earth's crust over large areas, and perhaps everywhere, approaches a state of isostatic equilibrium, and that isostatic compensation is probably complete at a depth of only 76 miles. Hayford's results have been ably supported and applied by my predecessor, Doctor Becker, in his address last year; but some geologists hesitate to accept them. Barrell, after an elaborate discussion of the whole question, thinks the equilibrium much less complete than Hayford's results would suggest; but his arguments do not seem entirely convincing.[17] Great stress is laid on the submarine deltas of the Nile and

[17] Articles on the strength of the earth's crust. Jour. Geol., vols. xxii and xxiii.

the Congo as loads which should have depressed the floor on which they were laid down, but have not done so. It should be remembered, however, that we know them only from soundings, and that assumptions regarding them are more or less hypothetical. On the other hand, the delta of the Mississippi seems to conform to the theory of isostasy, and there are numerous examples of depression going hand in hand with the formation of shallow-water deposits quite in accord with the isostatic theory. The 14,000 feet of coal measures at the Joggins are an instance. But more convincing still is Fairchild's demonstration that a wave of elevation followed up the retreat of the ice-front during the closing stages of the Glacial period. The thickness of ice near its margin could not have been more than a few thousand feet, perhaps half a mile, which would mean in weight of rock only 750 feet. If the stiff carapace of the earth in the State of New York yielded to so slight a change of load, it is hardly credible that 9,900 feet of sediments spread over 75,000 square miles of sea-bottom off the coast of Africa could have no effect.

If I understand Barrell's discussion aright, his differences from Hayford's conclusions are rather of degree than of kind. He thinks the earth's crust more rigid and considers adjustments to change of load much less complete, and also that they are carried out by slow movements in the "asthenosphere" much below Hayford's level of complete compensation at 76 miles below the surface.

He would probably agree that on the broad scale continents are buoyed up because they are light, and ocean bottoms are depressed because the matter beneath them is heavy. He would admit that to transform great areas of sea-bottom into land it would be necessary either to expand the rock beneath by several per cent or to replace heavy rock, such as basalt, by lighter materials, such as granite. There is no obvious way in which the rock beneath a sea-bottom can be expanded enough to lift it 20,000 feet, as would be necessary in parts of the Indian Ocean, to form a Gondwana Land; so one must assume that light rocks replace heavy ones beneath a million square miles of the ocean floor. Even with unlimited time, it is hard to imagine a mechanism that could do the work, and no convincing geological evidence can be brought forward to show that such a thing ever took place.

Discussing this question not long ago in the Journal of Geology, Professor Chamberlin showed that the only typical case of deep-sea deposits found on land, the well known one of the Barbados, occurs on one of the great hinge lines around which motions of the earth's crust take place and has no real bearing on the change of ocean bottoms to continents.[18]

[18] Jour. Geol., vol. xxii, pp. 131, etc.

The same may be said of the deep-sea deposits on Timor, in the East Indies, recently described by Molengraaff.[19] In position Timor is almost the counterpart of the Barbados in the West Indies.

The distribution of plants and animals should be arranged for by other means than by the wholesale elevation of ocean beds to make dry-land bridges for them. W. D. Matthew's excellent paper on climate and evolution suggests ways in which this may be done more economically.

The elevation of mountain chains by folding or the overriding of blocks might be expected to make trouble for the isostatic theory; but the two best known examples, the Rockies and the Himalayas, seem to be approximately in isostatic equilibrium. In the case of the Himalayas, the youngest and highest of the great mountain systems, it is staggering to find nummulitic beds 20,000 feet above the sea; but, however it was managed, enough light material seems to have been introduced beneath to float the mountains at about the proper height.

We may conclude that, broadly speaking, the dry-land areas have always been where they are now. The adjustments of the boundaries of land and sea have been confined to the margins of the continental masses.

Teleological Considerations

There are certain teleological features of the relations of land and water to which attention may be drawn in closing. Without water, no life such as we know would be possible. On the other hand, uniformly deep water over the whole earth, such as might have been expected in a rigidly mechanical scheme, would probably not have provided the conditions necessary for the development of life. An apparently accidental lack of homogeneity in the earth allows lighter parts to rise above what would otherwise have been a universal sea. The combined efforts of the epigene forces since the earliest known times have been directed toward the destruction of continents and islands and their reduction to shoals completely covered by the sea, but their efforts have always been foiled by movements originating in the earth's interior. No continent seems to have been completely submerged since Triassic times. The life of land plants and animals appears to have been uninterrupted since that time on all the continents.

There has been perpetual oscillation in respect to the area and elevation of land exposed, but on the whole the balance has been carefully maintained. But for the presence of oceans of water, of an abnormal lightness in some parts of the earth's crust, and an unfailing balance for 50,000,000 years between the forces of elevation and of destruction, life such as ours would have been impossible. Can we look on these surprising adjustments as merely accidental?

[19] Koninklijke Akad. v. Wetenschappen, Amsterdam, deel xxiv, pp. 415-430.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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HYPERSTHENE SYENITE AND RELATED ROCKS OF THE BLUE RIDGE REGION, VIRGINIA [1]

BY THOMAS L. WATSON AND JUSTUS H. CLINE

(Presented before the Society December 29, 1914)

CONTENTS

[1] Manuscript received by the Secretary of the Society December 6, 1915.

Introduction

The Blue Ridge, which forms the extreme eastern member of the Appalachian Mountains, constitutes one of the principal topographic divisions of the Appalachian ranges. In Virginia the Blue Ridge Mountains form a fairly continuous and well defined ridge extending from Harpers Ferry southwestward entirely across the State. At Harpers Ferry the Blue Ridge Mountains are narrow, and in elevation are less than 1,000 feet above sealevel; but southwestward through Virginia the ridge becomes broader and higher, and attains its greatest width in North Carolina. Heights of more than 4,000 feet above the sea are reached at several points in Virginia.

The Blue Ridge is composed of a central core of igneous rocks, flanked on the northwest side by the folded sedimentary series of Cambro-Ordovician rocks of the Great Valley province. The basal member of this series is a quartzite (Weverton), which extends for much of the distance as a range of hills along the west flank of the main ridge at an altitude equal in some cases to that of the Blue Ridge. Remnants of the Cambrian series of sediments are also preserved in places along the southeast slope of the Blue Ridge and at several points in the vicinity of James River Gap. The sediments are arched in anticlinal fashion entirely over the ridge, completely concealing for short distances the central core of igneous rocks. The southeast slope merges into the Piedmont Plateau, along which, in places, are groups of outlying low ridges that have been isolated by erosion from the main ridge, but exhibiting as a rule similar rock types.

In the middle and northern parts of the Blue Ridge and the adjacent portions of the Piedmont Plateau in Virginia one of the dominant igneous rocks of granitoid type is a quartz-bearing pyroxene syenite. The igneous complex, of which pyroxene syenite is the chief type, may represent a Precambrian batholithic intrusion, exposed at intervals for a distance of 150 miles in a belt up to 20 miles or more in width. Differentiation of the syenite magma has given rise to a variety of related rocks, some of which are of particular interest.

Studies of the igneous complex forming the central core of the Blue Ridge in middle and northern Virginia are sufficiently advanced to indicate that the rock types exhibit certain kinships which mark them as differentiates from a common magma, and that this igneous complex, designated by the writers as the Blue Ridge petrographic province, shows certain important differences in mineralogy and chemistry from the igneous rocks which enter into the composition of the Piedmont Plateau to the east.

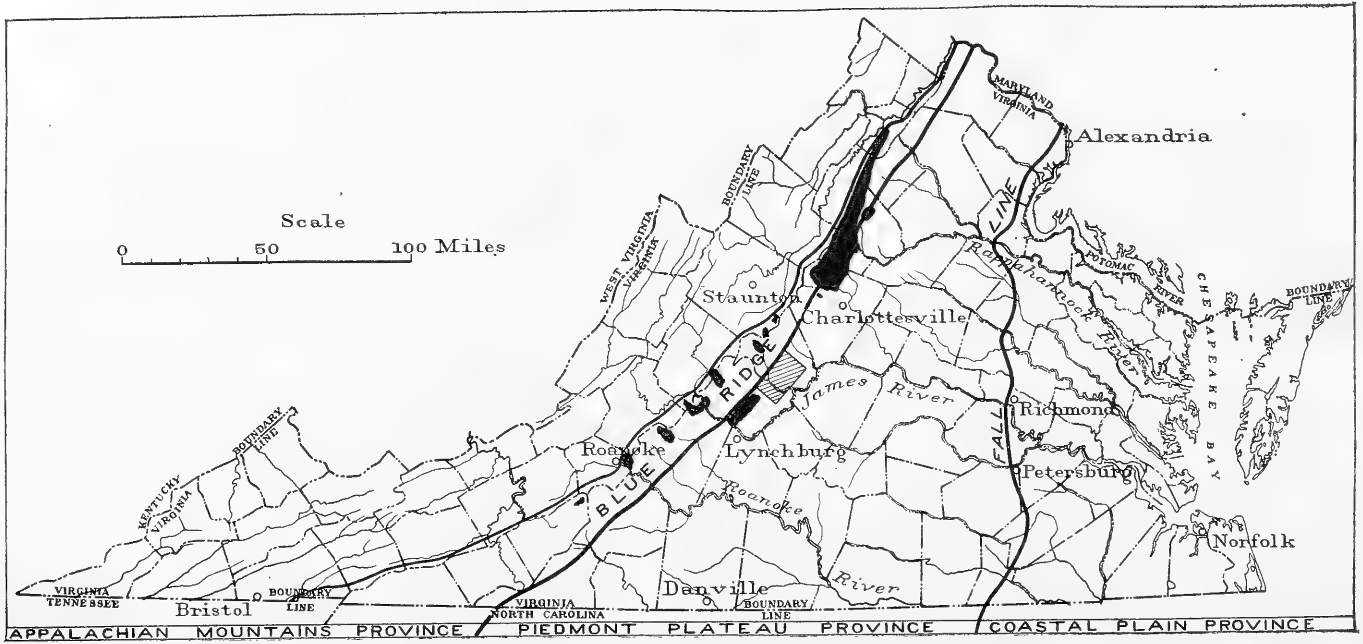

FIGURE 1.—*Outline Map of Virginia*

Showing location of hypersthene-andesine syenite in black and the Amherst-Nelson counties comagmatic area in parallel ruled lines

The results presented in this paper are based on field and laboratory investigations of the igneous complex which forms the central core of the northern and middle Blue Ridge region and the adjacent portions of the extreme western margin of the Piedmont Plateau, undertaken at brief intervals during the past ten years. The scope of the paper is limited to a petrographic study of this igneous complex, since a complete discussion of the Blue Ridge igneous complex can not be attempted in advance of a thorough investigation of the field relationships. The principal claim for this study, therefore, is as a contribution to the petrography of the Blue Ridge geology.

Previous geologic Work

Probably the first reference to the syenites of the Blue Ridge in Virginia was by Prof. William Barton Rogers[2] in his annual reports on the *Geology of the Virginias* from 1835 to 1841. He refers to the occurrence of syenitic rocks at various places in the Blue Ridge, notably in the James River and Tye River gaps, and makes special reference to the pronounced porphyritic texture of the syenite in Tye River Gap.

During his early work in Virginia Prof. William M. Fontaine devoted considerable time in the field to study of the Blue Ridge syenites. Only occasional reference is made to their occurrence in his publications, yet the degree to which they attracted his attention is shown by the large collection of the rocks which he made from different parts of the Blue Ridge and adjacent portions of the Piedmont Plateau. These collections are preserved in Brooks Museum at the University of Virginia and have been freely used in this study.

In 1884, Professor Fontaine sent to the United States National Museum specimens of unakite from Milams Gap, in Page and Madison counties, Virginia, and later, in 1913, specimens of the associated syenite. This led to the first petrographic description of these rocks in 1904 by Mr. W. C. Phalen,[3] who designated the syenite of the Page-Madison counties area as hypersthene akerite because of its similarity to the akerites of Norway described by Brögger.

In 1894, Mr. Arthur Keith[4] mapped the syenite occurring southwest of Front Royal along the extreme western side of the crystalline belt as granite, six varieties of which he distinguished and described in the Blue Ridge region. Keith's description of one of the varieties follows:

[2] See a reprint of annual reports and other papers on the geology of the Virginias, by William Barton Rogers, 1884, 832 pages.

[3] W. C. Phalen: A new occurrence of unakite. Smithsonian Miscellaneous Collections, vol. 45, 1904, pp. 306-316.

[4] Arthur Keith: Geology of the Catoctin Belt. Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, part ii, pp. 285-395.

"Granite from one mile northwest of Browntown, Virginia, shows quartz, orthoclase, plagioclase, hornblende, a little biotite, magnetite, and, along the feldspar cleavage, chlorite. Another specimen from the same locality shows the same minerals in larger crystals. A third specimen contains a large amount of garnet in rude crystals and fragments, a little apatite and pyrite, and but very little orthoclase" (page 300).

In 1906, Weed and Watson[5] described the coarse-grained hypersthene syenite traced by them at irregular intervals along the west side of the Blue Ridge from Dickeys Hill, south of Front Royal, in Warren County, southward to Hightop and beyond in Greene County. Farther southwest, at Stony Man, they stated that the field relations indicated the syenite to be of later age than the Catoctin schist, which is regarded as Algonkian.

In 1907, Watson[6] published a brief discussion of hypersthene syenite and associated hornblende norite from a locality in the northern part of Floyd County, Virginia. Attention was called to the close similarity of the syenite from Floyd County to the unakite-bearing syenite at Milams Gap, in Page and Madison counties, more than 100 miles to the northeast, and to similar syenites of Norway.

In 1913, Watson and Taber[7] published a detailed discussion, including descriptions of a syenite-norite-nelsonite series of rutile-bearing rocks in Amherst and Nelson counties, Virginia, and of the hypersthene syenite occurring on the west slope of the Blue Ridge farther southwest in Roanoke County. The Amherst-Nelson counties rock series shows striking relationships in mineralogy and chemistry to the granite-syenite-norite series of the Blue Ridge igneous complex of the larger Blue Ridge province.

Quartz-bearing Hypersthene-Andesine Syenite

DISTRIBUTION

Quartz-bearing hypersthene syenite is one of the most abundantly occurring granitoid rocks in the central Blue Ridge region. It has been observed in the Blue Ridge and adjacent portions of the Piedmont Plateau in numerous exposures distributed over a distance of about 150 miles in a northeast-southwest direction (see map, figure 1). The maximum distance between extreme occurrences along a direction (northwest-southeast) normal to the axis of the Blue Ridge will probably not exceed 30

[5] W. H. Weed and T. L. Watson: The Virginia copper deposits. Economic Geology, vol. i, 1906, pp. 309-330; see especially pp. 318-319.

[6] Thomas L. Watson: The occurrence of nickel in Virginia. Trans. Amer. Inst. Mng. Engrs., 1907, pp. 306-316; Mineral Resources of Virginia, 1907, pp. 31-33, 580-582.

[7] Thomas L. Watson and Stephen Taber: Geology of the titanium and apatite deposits of Virginia. Bull. III-A, Virginia Geol. Survey, 1913, 308 pages; see also Bull. 430, U. S. Geol. Survey, 1910, pp. 200-213.

miles. The most southwesterly known exposure of the syenite is in Floyd County and the most northeasterly one is in Warren County, a short distance south of Front Royal. Exposures of the rock have been observed in every county of the Blue Ridge region between Floyd and Warren counties.

The syenite frequently occurs in the northwest slope of the Blue Ridge, where it may form the basement on which the Lower Cambrian sediments rest. Usually it is more abundantly exposed on the southeast slope of the ridge, since in this position the Cambrian sediments have been removed to a large extent by erosion. It is not restricted, however, in distribution to the slopes of the Blue Ridge, but is noted in many localities in the most elevated portions of the ridge. Along the western margin of the Piedmont Plateau hypersthene syenite is the chief rock, forming Tobacco Row Mountain in Amherst County, and is also noted in similar positions in Madison and Greene counties. Hypersthene syenite forms the Peaks of Otter, and it is very abundant in James River Gap and vicinity, where it makes up large portions of the central core of the Blue Ridge.

MEGASCOPIC CHARACTER

Normally the hypersthene syenite is of greenish color, which varies in shade from a moderately light greenish to a dark greenish gray rock. It shows granitic texture, which varies from medium fine to coarse granular, and having usually a pronounced greasy or waxy appearance. In places the rock is porphyritic in texture, with phenocrysts of orthoclase, rarely of pyroxene. Variation in color of the fresh rock is noted, dependent on the relative proportions of the felsic and mafic minerals, the former varying in amount from 75 per cent to 92 per cent. In structure the rock is usually massive, but in places indistinct to pronounced foliation is shown, due to the effects of pressure metamorphism. Weathered surfaces are usually deeply pitted from inequality of resistance of the component minerals, and the rock yields on complete decay a reddish brown soil which is quite fertile.

The syenite is composed essentially of orthoclase (microcline), plagioclase, and pyroxene, each of which may be recognized in hand specimens. Feldspar is the most abundant constituent of the rock and is usually of dark greenish gray color, with glistening cleavage surfaces, but decidedly waxy on fracture surfaces. Quartz is nearly always present, but in varying amount, some specimens showing very little, while others contain considerable. Biotite occurs in places and in several localities it is present in sufficient amount to be designated a characterizing accessory. There are facies of the rock in which hornblende is an important con-

stituent. Garnet of red color is developed in grains and crystals of the syenite of certain localities in Roanoke County and of those in Greene and adjoining counties in the northern Blue Ridge.

MICROSCOPIC CHARACTER

Normative feldspar ranges in amount from 56 per cent to 66 per cent. The varieties of orthoclase, microcline, albite, and calcic andesine make up the feldspar content of the rock. Of these andesine is the chief feldspar, although orthoclase or microcline may equal or exceed it in amount in some thin sections. Like the rocks of other areas which it most closely resembles and with which it is compared in subsequent pages of this paper, a noteworthy feature of the soda-lime feldspars in the rock is the frequent absence of twinning lamellæ, which might readily be mistaken for orthoclase. Microcline is the dominant variety of feldspar in some thin sections. Albite occurs in most thin-sections studied, not as separate individuals, but intergrown with the potash varieties as mocroperthite. Andesine is developed in anhedral forms and is frequently twinned, both on the albite and pericline laws. Its composition, determined by Larsen on four specimens of the rock collected from different localities, by measurements on the rhombic section and of the index of refraction, is as follows:

I	Ab_1An_1
II	$Ab_{63}An_{37}$
III	$Ab_{62}An_{38}$
IV	$Ab_{70}An_{30}$
V	$Ab_{67}An_{33}$

I. Specimen of syenite collected near the southeast foot of the Blue Ridge, in Browns Gap, Albemarle County, Virginia.

II. Specimen of syenite collected near the southeast foot of Tobacco Row Mountain, in the vicinity of Elon, Amherst County, Virginia.

III. Specimen of syenite collected on northwest slope of the northern Blue Ridge, near the boundary between Madison and Greene counties, Virginia.

IV. Specimen of syenite collected from the base of northeast slope of the Peaks of Otter, Bedford County, Virginia.

V. Specimen of syenite collected 1½ miles east of Vinton, Roanoke County, Virginia.

A comparison of these results clearly shows that the dominant variety of soda-lime feldspar (plagioclase) present in the rock of widely separated occurrences is very uniform in composition, corresponding in each case to a calcic andesine. It is important in this connection to note that the

feldspar-bearing members of the titanium-bearing series of rocks[8] in Amherst and Nelson counties, Virginia, which forms a part of the larger Blue Ridge petrographic province, contain as the dominant feldspar a calcic andesine of similar composition to that of the rock here described. The relationship of these rocks is discussed later.

Computing the feldspar composition in the usual way from analyses of the syenite given on page 202, the results may be tabulated as follows:

Normative Feldspar Composition of the Blue Ridge, Virginia, Hypersthene Syenite

	I	II	III	IV	V
Orthoclase	21.68	25.02	22.24	7.78	22.80
Albite	28.82	20.44	20.44	37.20	23.58
Anorthite	15.57	15.29	13.34	10.29	18.35
Total plagioclase	44.39	35.73	33.78	47.49	41.93
Total feldspar	66.07	60.75	56.02	55.27	64.73
Orthoclase-plagioclase ratio	1 to 2	1 to 1.4	1 to 1.5	1 to 6	1 to 1.8

An examination of this table shows that the ratio of normative orthoclase (microcline) to normative plagioclase ranges from 1 : 1.4 to 1 : 6, a variation which is in agreement with measurements made on thin sections under the microscope. The feldspar frequently exhibits distinct evidence of pressure metamorphism in bent and broken lamellæ of plagioclase, optical disturbance, and in some cases granulation.

Pyroxene is the chief mafic constituent of the syenite. Both orthorhombic and monoclinic varieties occur, the former being dominant in most cases. Augite may fail in a few thin sections of the rock, but hypersthene very rarely. The two pyroxenes are frequently intergrown with each other. They are very similar in color and can only be distinguished in many cases by their optical properties.

The optical properties prove hypersthene to be the orthorhombic pyroxene present. It varies from colorless to reddish, exhibiting fairly strong absorption in the more deeply colored forms of the mineral. It is developed in stout, irregular-shaped forms, usually elongated in the direction of the *c* axis and frequently containing rounded inclusions of apatite and ilmenite. Platelike inclusions are abundantly developed in both the monoclinic and orthorhombic pyroxenes of some thin sections.

The hypersthene is pleochroic in shades, varying from reddish brown to pale yellowish brown. It alters into a fibrous pleochroic mineral, with the long axis of the fibers oriented parallel with the *c* axis of the hypersthene. Measured on the long axis of the fibers, the extinction is about

[8] T. L. Watson and S. Taber: Geology of the titanium and apatite deposits of Virginia. Bull. III-A, Virginia Geol. Survey, 1913.

10 degrees, and the mineral has been identified as uralitic hornblende. The alteration takes place about the margin of the hypersthene and along fracture and cleavage lines. In extreme cases of alteration the change is accompanied by the development of much free iron oxide. The monoclinic pyroxene present is augite, which frequently exhibits a well developed diallage parting parallel to 100, especially in the more basic facies of the rock.

Quartz is present in all the thin sections, but the quantity is very variable; in some it is a very minor accessory, in others it is an important constituent. The principal occurrence of quartz in the rock is as irregular grains of variant size, being the last product of crystallization filling the interstices between the other minerals. It is also developed as rounded inclusions in the feldspar and as graphic intergrowths with both feldspar and hornblende. The quartz-hornblende growths are in all respects like the common micrographic intergrowths of quartz and feldspar. In the five analyses made of the rock from different localities in the Blue Ridge normative quartz is large in amount, ranging from 14.76 per cent to 25.44 per cent. Without exception the quartz of the hypersthene syenites discussed in this paper is some shade of gray in color and does not contain abundant inclusions of rutile needles, as the blue quartz of the quartz-bearing rocks of the Amherst-Nelson counties rutile area and of some granitoid rocks in the northern Blue Ridge region.

Biotite is sometimes developed in the syenite, both as an original and as a secondary constituent. The pyrogenetic biotite is of the ordinary brown variety, possessing strong absorption and good cleavage, and does not exhibit any unusual characters. In neither occurrence, however, is the mineral usually abundant; in fact, it was observed only in a few thin sections. At one or two places in the Browns Gap section, Albemarle County, biotite, as an original mineral, is rather plentifully distributed through the syenite, both in hand specimens and in thin sections.

Hornblende occurs as an original mineral in some thin sections of the syenite and is usually very fresh. Secondary hornblende (uralite) is also formed at times as an alteration product from the hypersthene. The primary hornblende is developed in irregular-shaped masses of fair size and to some extent in small grains. The angle between c and z is nearly 20°. Pleochroism is strong: $x =$ pale yellowish brown, $y =$ brown, and $z =$ deep reddish brown. The hornblende frequently exhibits intergrowths with quartz which strongly resemble granophyric structure in feldspar and quartz. In some phases of the rock hornblende-quartz intergrowths are quite common.

Apatite, magnetite, titanite, zircon, and pyrite were identified in nearly

every thin section. Of these lesser minerals, apatite and magnetite are the most important, because of their constant presence in greater or less amount in all thin sections studied. Apatite occurs in anhedral and euhedral forms as inclusions in other minerals, while magnetite is developed in grains of fairly large size and commonly shows alteration to leucoxene, both along the border and along the fracture lines. Rutile is rare except as needlelike inclusions in the felsic minerals.

CHEMICAL COMPOSITION AND CLASSIFICATION

The chemical composition of the Blue Ridge hypersthene syenite is shown in the five analyses of the subjoined table made on specimens of the rock collected from as many different localities. The variation in silica of nearly 8 per cent is due chiefly to the variable amount of quartz in the rock as confirmed by microscopic study. The alkalies, soda and potash, show some variation; but in all cases, except IV, which is dosodic, the rock is sodipotassic. Titania and phosphoric anhydride, especially the former, are high for this type of rock, characteristic features, but more emphasized in the composition of the Amherst-Nelson counties comagmatic area of the same general region.

Analyses of Hypersthene Syenite from the Blue Ridge Mountains, Virginia

	I	II	III	IV	V
SiO_2	68.21	65.88	63.76	61.08	60.52
Al_2O_3	15.33	14.15	13.04	12.43	*a* 16.99 [9]
Fe_2O_3	.81	.77	1.36	1.86	.60
FeO	3.62	5.29	5.64	6.66	6.53
MgO	.68	1.48	1.37	1.44	1.59
CaO	2.90	3.42	4.30	5.32	4.58
Na_2O	3.38	2.42	2.36	4.42	2.83
K_2O	3.72	4.19	3.76	1.34	3.91
H_2O-	.14	.23	.10	.06	.88
H_2O+	.33	.41	.14	.37	.....
TiO_2	1.01	1.75	2.85	4.26	n. d.
P_2O_5	.42	.39	.88	1.01	.74
MnO	none	.33	.19	.41	.25
BaO	none	none	none	none	.....
CO_2	none	none	none	none	.....
S	trace	none	.06	.09	.....
	100.15	100.71	100.11	100.75	99.42

I. Hypersthene syenite from the southeast foot of the Blue Ridge, in Browns Gap, Albemarle County, Virginia. J. G. Dinwiddie, analyst.

a Includes TiO_2.

[9] Watson and Taber: Bull. III-A, Virginia Geological Survey, 1913.

II. Hypersthene syenite near the southeast foot of Tobacco Row Mountain, in the vicinity of Elon, Amherst County, Virginia. J. G. Dinwiddie, analyst.

III. Hypersthene syenite from the northwest slope of the Blue Ridge near the boundary of Madison and Greene counties, Virginia. J. G. Dinwiddie, analyst.

IV. Hypersthene syenite from the base of the northeast slope of the Peaks of Otter, Bedford County, Virginia. J. G. Dinwiddie, analyst.

V. Hypersthene akerite (syenite) from Milams Gap, Page and Madison counties, Virginia. W. C. Phalen, analyst.

Norms corresponding to Analyses of Rocks on page 202

	I	II	III	IV	V
Q	25.44	23.52	24.78	19.80	14.76
Or	21.68	25.02	22.24	7.78	22.80
Ab	28.82	20.44	20.44	37.20	23.58
An	15.57	15.29	13.34	10.29	18.35
Di	.....	.68	2.54	8.57	.....
Hy	4.26	9.97	6.63	3.42	13.80
Il	1.98	3.51	5.47	8.21	2.28
Mt	1.16	1.16	2.09	2.78	.93
Ap	.91	.91	1.86	2.17	1.55
Pr	.....	.....	.24	.36	.....
Incl	.47	.64	.54	.43	.88

Summary of Classification

Number.	Symbol.	Magmatic name.
I	I. 4. 3(2). 3.	amiatose
II	II. 4. 3. 3.	harzose
III	II. 4. 3(2). 3.	harzose
IV	II. 4. 2. 4.	dacose
V	II. 4. 3. 3.	harzose

Mineralogically the rock is characterized by (1) calcic andesine as the chief feldspar with notable amounts of alkali feldspar developed in part as microperthite; (2) a variable but frequently a considerable amount of quartz, and (3) orthorhombic (hypersthene) and monoclinic (augite) pyroxenes with very subordinate biotite, which becomes the chief mafic mineral in several localities, and sometimes a little hornblende.

From the microscopic study of a large number of thin sections covering all known exposures the rock is quite uniform in mineral composition, but considerable variation in the proportions of the principal minerals is indicated. Confirmation of this variation is shown in the three subrang positions of the rock in the Quantitative System as determined by five analyses made on specimens from different localities. The norms corresponding to the five analyses made of the rock indicate in each case more

normative plagioclase than normative orthoclase. Determinations of the plagioclase conclusively prove it to be andesine. Based, then, on the fact that the chief feldspar is andesine, with considerable but less alkali feldspar (orthoclase), the normal facies of the rock should be designated a *pyroxene-granodiorite.* According to the usage of many petrographers, the rock would be grouped as a pyroxene-quartz monzonite, with which it is compared on pages 204-206. Because of the notable amount of potash feldspar present, which may equal or exceed soda-lime feldspar in some thin sections of the rock from some localities, but not in the norms calculated from the five analyses in the table on page 202, the rock may also be classed as a *quartzose-pyroxene-andesine syenite.* However the rock may be grouped, it is entirely clear that it is a transitional or intermediate type.

As indicated both by microscopic study of thin sections and by the table of norms on page 203 (I to V), alkali feldspar is present in notable amount, being in all cases but one (IV) three-fifths of the lime-soda feldspar, and therefore sodipotassic in four (I, II, III, and V) and dosodic in one (IV). Considered further from the quantitative point of view, three analyses (II, III, and V) of the rock place it in the alkalicalcic rang tonalase and the sodipotassic subrang *harzose,* one (I) in the alkalicalcic rang coloradase and the sodipotassic subrang *amiatose,* and one (IV) in the domalkalic rang dacase and the dosodic subrang *dacose.*

COMPARISON WITH QUARTZ MONZONITE

Origin and application of name.—Monzonite was the name first given by de Lapparent in 1864 to rocks of Monzoni, composed essentially of orthoclase and andesine with subordinate pyroxene. Brögger applied the term in 1895 to a transitional or intermediate group of phanerites between syenite and diorite having approximately equal amounts of alkali feldspar and lime-soda feldspar with any kind of mafic mineral in subordinate amount. The name quartz monzonite[10] would apply to any quartz-rich monzonite and would stand in the same relation to the granite-quartz diorite groups as monzonite does to the syenite-diorite groups.

In his discussion of the chemical composition of quartz monzonite and granodiorite Iddings[11] suggests "that the name *quartz monzonite* be applied to varieties in which orthoclase exceeds the lime-soda feldspars, and

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[10] The name grandiorite, given by Becker and Lindgren in 1891 to the granitic rocks of the Sierra Nevada in California intermediate between granites and quartz diorites, is considered by some petrographers as synonymous with quartz monzonite. Brögger uses the term adamellite for acid quartz monzonites or for quartz monzonites as designated by Iddings. Igneous rocks, vol. ii, 1913, p. 61. See in this connection Bull. 426, U. S. Geol. Survey, 1910.

[11] J. P. Iddings: Igneous rocks, vol. ii, 1913, p. 69.

that *granodiorite* be used for those rocks in which lime-soda feldspar exceeds orthoclase." Concerning their quantitative relations, he says: "Distinguishing quartz monzonites from granodiorites by the relative amounts of orthoclase and lime-soda feldspar, it will be convenient to limit the term quartz monzonite to those rocks of this group in which orthoclase exceeds lime-soda feldspar up to the ratio of 5:3, and to confine the term granodiorite to those in which lime-soda feldspar exceeds orthoclase up to the ratio of 5:3."

Chemical composition.—There are given in the table below five analyses of quartz monzonites (one each from Idaho, Colorado, California, and Montana, and an averaged analysis of 20 analyses from various localities) for comparison with the five analyses of the Blue Ridge, Virginia, type on page 202. The rocks are all sodipotassic; and I, II, and III correspond to the subrang name toscanose, and IV to amiatose.[12] Each one (I, II, III, and IV) has been described as quartz monzonite, but, following Iddings, they would belong chemically with granodiorite rather than with quartz monzonite. The correspondence nevertheless with the Virginia type is very close, except IV, page 202, which is clearly a quartz diorite. In each case the rocks are characterized by considerable alkali feldspar and a larger amount of lime-soda feldspar of andesine composition. According to the grouping by Iddings, the Virginia type corresponds more closely to granodiorite than to quartz monzonite.

Analyses of Quartz Monzonites

	I	II	III	IV[13]	V
SiO_2	68.42	66.83	65.70	63.88	67.41
Al_2O_3	15.01	15.24	15.31	15.84	15.76
Fe_2O_3	.97	2.73	2.54	2.11	1.93
FeO	1.93	1.66	1.62	2.50	1.96
MgO	1.21	1.63	1.62	2.13	1.43
CaO	2.60	3.59	2.56	3.97	3.54
Na_2O	3.23	3.10	3.62	2.81	3.45
K_2O	4.25	4.46	4.62	4.23	3.74
H_2O+	.73	.56	.42	.66	.....
H_2O-	.54	.....	.17	.22	.....
TiO_2	.50	.54	.72	.65	.51
P_2O_5	.13	.18	.33	.21	.19
MnO	.06	.10	trace	.07	.06
BaO	.12	.11	.12	.09	.....
Incl	.25	.09	.18	.36	.....
	99.95	100.82	99.53	99.82	100.00

[12] Near harzose.

[13] Two other analyses of the quartz monzonite (granite) from Butte correspond to the subrang name harzose, as do three of the five analyses of the Virginia type. Compare this analysis with the analyses of the Virginia type on page 202.

I. Quartz monzonite from Hailey, Idaho. W. F. Hillebrand, analyst. W. Lindgren: Twentieth Annual Report, United States Geological Survey, 1900, part iii, page 91.

II. Quartz monzonite, near San Miguel Peak, Telluride, Colorado. H. N. Stokes, analyst. W. Cross: Telluride Folio, United States Geological Survey, 1899, page 6.

III. Quartz monzonite, Nevada Falls Trail, Yosemite Valley, California. W. Valentine, analyst. H. W. Turner: Journal of Geology, volume vii, 1899, page 152.

IV. Granite (quartz monzonite), Walkerville Station, Butte, Montana. H. N. Stokes, analyst. W. H. Weed: Journal of Geology, volume vii, 1899, page 739.

V. Average quartz monzonite, twenty analyses averaged. R. A. Daly: Igneous rocks and their origin, 1914, page 386.

Norms corresponding to Analyses of Quartz Monzonite on page 205

	I	II	III	IV	V
Q	25.1	22.2	19.1	19.3	22.98
Or	25.6	26.7	27.2	25.0	22.24
Ab	26.7	26.2	30.4	23.6	29.34
An	13.1	14.2	12.1	18.1	16.68
C	.3	....	.4	....	.....
Di	....	2.6	....	1.3	.....
Hy	5.0	3.4	4.1	6.7	4.95
Mt	1.4	3.9	3.5	4.2	2.78
Il	.9	1.1	1.4	....	.91
Ap	....	....	....	....	.31

Normative Feldspar Composition

	I	II	III	IV	V
Total plagioclase	39.8	42.5	40.4	41.7	46.02
Total feldspar	65.3	69.7	67.1	66.7	68.26
Ab_nAn_m	2:1	2.5:1	1.8:1	1.3:1	1.8:1
Orthoclase-plagioclase ratio	1 to 1.5	1 to 1.6	1 to 1.5	1 to 1.7	1 to 2.1

COMPARISON WITH AKERITE [14]

In 1914, Phalen[15] applied the name hypersthene akerite to the rock from Milams Gap, in Page and Madison counties, Virginia, because of

[14] The name akerite was proposed by Brögger (Zeitsch. f. Kryst., vol. xvi, 1890, p. 43) for a variety of syenite at Aker, Norway, consisting of orthoclase, much plagioclase, biotite, augite, and some quartz. Rocks referred to this type have been described as plagioclase-augite syenite, whose feldspars are soda microcline and lime-soda feldspar. According to Iddings (Igneous rocks, vol. ii, 1913, p. 164), they may also be classed as soda monzonites. The akerites show wide variation in composition and belong to different groups.

[15] W. C. Phalen: A new occurrence of unakite—a preliminary paper. Smithsonian Miscellaneous Collections, vol. 45, 1904, p. 311.

its close resemblance in composition to Brögger's hypersthene akerite[16] from Barne Kjern See, Norway. The resemblance is admittedly close, but unfortunately the analysis of the rock from the Norway locality is rated by Washington[17] as inferior, and must be accounted therefore as having but slight comparative value.

For purposes of comparison we have selected the seven superior analyses of akerites listed by Washington, one each from Massachusetts and New York and five from Norway.

Analyses of Akerites from Massachusetts, New York, and Norway

	I	II	III	IV	V	VI	VII
SiO_2	66.60	66.13	63.45	62.35	59.56	58.48	58.00
Al_2O_3	15.05	17.40	18.31	19.50	17.60	19.24	16.91
Fe_2O_3	1.07	2.19	.42	3.05	2.90	5.75	3.29
FeO	4.42	n. d.	3.56	2.25	3.38	n. d.	3.74
MgO	.36	.04	.35	1.46	1.87	.99	1.96
CaO	2.21	.81	2.93	2.40	3.67	5.02	3.60
Na_2O	4.03	5.28	5.00	2.71	4.88	5.52	5.14
K_2O	5.42	5.60	5.15	3.28	4.40	3.06	5.20
H_2O-	.41	1.22	.30	.75	1.37	.47	.60
H_2O+	....	....		....	....	....	....
TiO_2	.76	.74	.07	1.25	1.22	.96	.85
P_2O_5	....	....	trace	....	....	....	....
MnO	trace	.13	none	.18	.03	trace	.80
BaO	none	....	.13	....	....	....	....
	100.33	99.54	99.73	99.18	101.32	99.41	100.09

I. Akerite, Gloucester, Massachusetts. H. S. Washington, analyst. Journal of Geology, volume vi, 1898, page 798.

II. Akerite (porphyritic) between Thinghoud and Fjelebua, Norway. R. Mauzelius, analyst. W. C. Brögger: Zeitsch. f. Kryst., volume xvi, 1890, page 46.

III. Augite syenite (akerite), Loon Lake, Franklin County, New York. E. W. Morley, analyst. H. P. Cushing: Bulletin of the Geological Society of America, volume 10, 1899, page 183.

IV. Akerite, Thinghoud, Norway. G. Särnström, analyst. W. C. Brögger: Zeitsch. f. Kryst., volume xvi, 1890, page 46.

V. Syenite (akerite, W. C. B.), Vettakollen, n. Kristiania, Norway. P. Jannasch, analyst. H. O. Lang: Nyt. Mag., volume xxx, 1884, page 40; see also W. C. Brögger: Zeitsch. f. Kryst., volume xvi, 1890, page 50.

VI. Akerite, Ramnas, Kristiania region, Norway. R. Mauzelius, analyst. W. C. Brögger: Zeitsch. f. Kryst., volume xvi, 1890, page 46.

VII. Akerite, Tuft, Laugendal, Norway. V. Schmelck, analyst. W. C. Brögger: Eg. Kg., volume ii, 1895, page 33.

[16] W. C. Brögger: Zeitsch. f. Kryst., vol. xvi, 1890, p. 50.
[17] H. S. Washington: Professional Paper No. 14, U. S. Geol. Survey, 1904, p. 389.

Norms of Akerites corresponding to Analyses of Rocks on page 207 [18]

	I	II	III	IV	V	VI	VII
Q	15.2	11.5	12.6	26.5	2.8	.7	....
Or	32.2	33.4	30.0	19.5	26.1	18.3	30.6
Ab	34.1	44.5	37.2	23.1	41.4	45.6	43.0
An	7.0	2.8	9.7	12.0	13.1	19.2	7.8
C	....	1.6	....	7.0	....	....	....
Ne	....	....	....	....	....	....	.3
Ol	....	....	....	....	....	....	2.7
Di	3.4	....	3.0	....	4.5	5.0	8.2
Hy	5.0	2.7	2.8	3.7	4.4	7.9	....
Il	1.3	1.4	.9	2.3	2.3	1.8	1.7
Mt	1.6	....	3.5	3.7	4.2	....	4.9
Hm	....	....	....	.5	....	....	....

Summary of Classification

Number.	Symbol.	Magmatic name.
I	I. 4. 2. 3.	toscanose
II	I. 5. 1. 3.	phlegrose
III	I. 5. 2. 3.	pulaskose
IV	I. 4. 2. 3.	toscanose
V	II. 5. 2. 4.	akerose
VI	II. 5. 2. 4.	akerose
VII	II. 5. 2. 3.	monzonose

Rocks belonging to the akerite type in Massachusetts are found chiefly in the eastern part of Essex County associated with granites and nepheline syenites. They have been described by Wadsworth,[19] Sears,[20] and Washington,[21] who agree in classing them with the quartz-bearing augite syenites. Washington compares his analysis of the akerite from Gloucester, Massachusetts (I of table of analyses, page 207), with one of akerite (porphyritic), described by Brögger,[22] occurring between Thinghoud and Fjelebua, Norway (II of table of analyses, page 207). He remarks that the Massachusetts rock shows close parallelism with the *more acid* of Brögger's akerites and belongs to an extreme type, since the akerites as a group are more basic. Although the analysis of the Massachusetts rock shows rather high lime, Washington states that this is all used up in the formation of pyroxene, leaving none for lime-soda feldspar, which the microscope shows is not present. This rock is an alkalic and sodic toscanose whose plagioclase is albite.

[18] H. S. Washington: Professional Paper No. 14, U. S. Geol. Survey, 1904.
[19] M. E. Wadsworth: Geol. Mag., 1885, p. 207.
[20] J. H. Sears: Bull. Essex Inst., vol. xxiv, 1892, and vol. xxv, 1893.
[21] H. S. Washington: Jour. Geol., vol. vi, 1898, pp. 787-808; see especially pp. 796-799.
[22] W. C. Brögger: Zeitsch. f. Kryst., vol. xvi, 1890, p. 55.

The rock from New York, represented by analysis III of table on page 207, is from Loon Lake, Franklin County, in the Adirondacks. It has been carefully studied and described by Cushing,[23] who compares it with the akerite described anew by Washington from Essex County, Massachusetts, and remarks that the two show great similarity, except that the Massachusetts rock lacks hypersthene. Cushing states that the rocks belong to the variety of augite syenite called "akerite" by Brögger and are quartzose augite syenites. They are clearly the more acid representatives of the syenite group.

Like the analyses of the Massachusetts and New York rocks, the five analyses of the Norway akerites (II, IV-VII, table of analyses, page 207) show a high alkali content, except IV (5.99 per cent), which is considerably lower than the other four and in which $K_2O + Na_2O$ ranges from 8.74 to 10.88 per cent. In the four analyses (III, V, VI, and VII) showing high alkalies the total normal feldspar exceeds 80 per cent in each case. In the Norway rocks normative plagioclase ranges in composition from andesine (IV) through sodic andesine (V and VI) to nearly albite (II and VII). One (II) is extremely and four (IV to VII) are dominantly alkalic, when the alkali-lime ratio is considered. Two (V and VI) are dominantly sodic and three (II, IV, and VII) have soda and potash in nearly equal proportions. Normative quartz is considerable in II and IV, 2.8 and 0.7 respectively in V and VI, and nil in VII. The position of the Norway akerites in the quantitative system, as shown on page 207, differs widely among themselves.

The Virginia rocks, on the other hand, contain a much lower alkali content and in general higher lime, the two being, with one exception (IV, page 202), in nearly equal proportions, and therefore alkalicalcic. The proportions of soda and potash in these four rocks are nearly equal. The normative feldspar ranges very much lower than in the Norway rocks; the dominant feldspar is a more calcic plagioclase (andesine), and normative quartz is uniformly higher. The mafic minerals are similar in kind for the Virginia and Norway rocks, except that hypersthene is a constant constituent of the Virginia rocks.

COMPARISON WITH SYENITE (ANDESINE ANORTHOSITE) OF NELSON COUNTY, VIRGINIA

The rocks of the Amherst-Nelson counties area[24] are igneous in origin and show in their mineral and chemical composition derivation from a

[23] H. P. Cushing: Bull. Geol. Soc. Am., vol. 10, 1899, pp. 177-192.

[24] For a detailed description of the geology of this area the reader is referred to Bull. III-A, Virginia Geol. Survey, 1913, by Watson and Taber.

common magma. They are characterized by prominence of apatite and the titanium minerals, ilmenite, rutile, and in a few places titaniferous magnetite; opalescent blue quartz; pyroxene (hypersthene) or secondary hornblende (uralite) derived from pyroxene as the dominant mafic mineral; and in most of the feldspar-bearing types by andesine antiperthite, with inclosed orthoclase (microcline) spindles as the dominant feldspar. They have been intensely, but unequally, metamorphosed, and in most of them complete or partial foliation has been developed.

The principal rock types that have been mapped by the Virginia Geological Survey include (1) biotite-quartz monzonite gneiss with variant schists, (2) syenite (andesine anorthosite), referred to as pegmatite in all publications previous to Bulletin III-A of the Virginia Geological Survey; (3) gabbro, (4) nelsonite, and (5) diabase. Intermediate gradations are observed between most of these types, and usually the dominant minerals in one type form the subordinate minerals in the others. Of the five rock types enumerated syenite is of most importance in this paper.

The syenite covers an area of about 20 square miles. It is, as a rule, closely crystalline and in places gneissoid or even schistose in structure. In some places along its southeastern border the rock exhibits abnormally coarse texture. It is composed chiefly of feldspar and blue quartz, but contains also, in places near the margin, pyroxene (hypersthene usually altered to hornblende), rutile, and lesser amounts of ilmenite and apatite. The ratio of these minerals varies greatly in different parts of the rock-mass, but feldspar is the dominant mineral, except in portions of the border zone. Two facies of the rock which apparently grade into each other are recognized—a feldspathic variety corresponding to dosodic *piedmontose* and a hornblendic variety, which is developed chiefly as a border zone and corresponds to dosodic *tonalose.* The central and larger portion of the mass consists almost exclusively of feldspar, with only scattered grains of blue quartz and scarcely any visible rutile or other minerals. The principal feldspar is a calcic soda variety (andesine) corresponding to about $Ab_{65}An_{35}$ and containing intergrowths of microcline oriented parallel to the twin lamellæ. In the feldspathic facies of the rock normative orthoclase (microcline) ranges from 16.68 to 23.35 per cent, with an average of 19.88 per cent. Total normative feldspar averages 88.63 per cent.

The composition of the syenite is shown in the chemical analyses given below, which should be compared with those of the Blue Ridge syenite on page 202.

Analyses of Syenite (Andesine Anorthosite), Nelson County, Virginia[25]

	I	II
SiO_2	60.44	57.06
Al_2O_3	23.02	14.54
Fe_2O_3	.29	1.49
FeO	.19	4.52
MgO	.21	4.10
CaO	5.59	4.37
Na_2O	4.94	3.13
K_2O	3.37	1.96
H_2O-	.08	.09
H_2O+	.32	1.32
TiO_2	1.11	7.10
P_2O_5	.15	.24
MnO	trace	.04
CO_2	trace	.09
S	trace	trace
	100.31	100.05

I. Average of four analyses of feldspathic facies of syenite (potash-bearing andesine anorthosite), Nelson County, Virginia. William M. Thornton, Jr., analyst. T. L. Watson: Bulletin 580-O, United States Geological Survey, 1914, page 399; for individual analyses see Watson and Taber: Bulletin III-A, Virginia Geological Survey, 1913, page 78.

II. Average of three analyses of hornblendic facies of syenite, Nelson County, Virginia. William M. Thornton, Jr., analyst. T. L. Watson: Bulletin 580-O, United States Geological Survey, 1914, page 399; for individual analyses see Watson and Taber: Bulletin III-A, Virginia Geological Survey, 1913, page 78.

Norms of Syenite corresponding to Analyses above

	I	II
Q	5.70	16.56
Or	20.02	11.68
Ab	41.40	26.20
An	28.36	19.74
C	.82	.....
Hy	.....	10.20
Il	.46	8.21
Hm	.32	.....
Mt	.....	2.09
Ru	.88	2.40
Tn	.....	.98
Ap	.31	.31

[25] For analyses and complete description of this rock see Bull. III-A, Virginia Geol. Survey, 1913, by Watson and Taber.

Summary of Classification

Number.	Symbol.	Name.
I	I. 5. 3. 4	piedmontose
II	II. 4. 3. 4	tonalose

When the Blue Ridge type of rock here described is compared with the rutile-bearing type of syenite (andesine anorthosite) of Amherst and Nelson counties, Virginia, the dissimilarity is seen to be equally as great as in the akerites, yet striking similarity in mineral composition in part is indicated. Both types are characterized by andesine as the dominant feldspar, but of a very unusual kind in the Nelson County rock, which is composed of andesine antiperthite with inclosed orthoclase (microcline) spindles. Feldspar intergrowths occur, but seem not to be characteristic of the main Blue Ridge type. Hypersthene, although largely altered to uralitic hornblende in the Nelson County rock, is a constituent of both types. Neither monoclinic pyroxene (augite) nor primary hornblende and biotite, mineral components of the Blue Ridge type, are known to occur in the Nelson County rock. Both types are quartz-bearing, but the quartz of the Blue Ridge rock is gray, while that of the Nelson County rock is deep blue, due to a crowding of its substance with abundant very minute needles of rutile, which are essentially absent from the quartz of the former type.

The dominant facies of the Nelson County rock is composed largely of feldspar, averaging more than 85 per cent of this mineral, the principal variety of which is andesine, with important amounts of orthoclase (microcline), ranging up to 20 per cent; subordinate quartz, and negligible amounts of mafic minerals. It is a rutile quartz-bearing anorthosite composed of andesine antiperthite and is a dosodic *piedmontose*. The border or hornblendic facies of the rock-mass contains less feldspar, the dominant variety of which is andesine, but more quartz of deep blue color, and considerable uralitic hornblende derived from hypersthene. This facies of the rock corresponds to a dosodic *tonalose*.

The rocks of the Amherst-Nelson counties comagmatic area, of which syenite (andesine anorthosite) is a principal type, are so related, both as to geographic position and broad geologic relations, as to leave no doubt of their belonging to the larger Blue Ridge petrographic province.

COMPARISON WITH PYROXENE SYENITE OF THE ADIRONDACKS

The Adirondack highland consists entirely of a Precambrian rock complex rimmed by early Paleozoics. The Grenville series, which is Precambrian, is the only sedimentary series yet recognized in the region, and, so far as known, it is older than the associated igneous rocks, which consist of anorthosites, syenites, granites, and gabbros—all more or less meta-

morphosed and some greatly so. The investigations of Professors Smyth, Kemp, Cushing, and Miller indicate extensive masses of syenite and granite to be the most abundant rocks in the Adirondack region. The granites are regarded as variants of the syenites.[26]

Miller has described the normal syenite of the Adirondacks as follows:[27]

"This rock shows a greenish-gray color when fresh and it weathers to a light brown. Its weathered surface is seldom more than a few inches thick. As regards structure and granularity, it is a quite variable rock. The granularity ranges from fine to fairly coarse, with a medium grain decidedly prevalent. A porphyritic texture is sometimes moderately developed. The structure ranges from only faintly gneissoid to very clearly gneissoid to almost schistose, this structure being accentuated by the arrangement (or flattening) of the dark-colored minerals, with their long axis parallel to the direction of the foliation. Evidence of crushing or granulation is common, though it varies greatly, the feldspars showing the effects of the granulation more than the other minerals.

"In mineral composition, too, the syenite is rather variable. Feldspars—microperthite, orthoclase, and soda-rich plagioclase—constitute 50 to 80 per cent of the rock. Quartz, in varying amounts up to 20 per cent, is always present. Pyroxene or hornblende, or both, occur in amounts up to 20 per cent. The pyroxene is mostly a green augite, with sometimes a little hypersthene. Hornblende is generally more abundant than pyroxene in the more quartzose syenites. From 1 to 5 per cent of magnetite always appears. Small amounts of zircon, zoisite, and apatite seldom fail. Garnet is much more sporadic in occurrence, though at times it makes up several per cent of the rock."

Cushing[28] states that, when traced from place to place, the syenite is quite a variable rock and becomes both more basic and more acidic than the normal type. Both are chiefly peripheral changes, though they may occur locally within the general mass. In its extreme basic facies the normal quartz syenite is of gabbroic composition, while in its acid facies variation into a rock of granitic composition with very abundant quartz is indicated. Megascopic descriptions of the Adirondack syenites by Cushing, Kemp, and Miller fit equally well the Blue Ridge type; also the variation in the amount of quartz in the normal type of the two regions, which mark the passage into a rock of gabbroic composition on the one hand and into one of granitic composition on the other, applies with equal force in the Virginia region.

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[26] For detailed descriptions of these rocks the reader is referred to the bulletins of the New York State Museum; also the following papers should be consulted:
C. H. Smyth, Jr.: Bull. Geol. Soc. Am., vol. 6, 1895, pp. 271-274.
H. P. Cushing: Bull. Geol. Soc. Am., vol. 10, 1899, pp. 177-192.
H. P. Cushing: Bull. Geol. Soc. Am., vol. 18, 1907, pp. 477-492.
H. P. Cushing: Amer. Jour. Sci., vol. 39, 1915, pp. 288-294.
W. J. Miller: Jour. Geology, vol. 21, 1913, pp. 160-180.
W. J. Miller: Bull. Geol. Soc. Am., vol. 25, 1914, pp. 243-263.

[27] W. J. Miller: Bull. Geol. Soc. Am., vol. 25, 1914, p. 245.

[28] H. P. Cushing: Bull. Geol. Soc. Am., vol. 18, 1907, p. 479.

Analyses of Syenites from the Adirondacks in New York

	I	II	III	IV	V	VI	VII	VIII	IX	X
SiO_2	54.10	59.70	61.01	62.41	63.45	64.47	65.65	66.35	66.72	68.50
Al_2O_3	17.45	19.52	15.36	18.75	18.38	10.51	16.84	14.09	16.15	14.69
Fe_2O_3	4.52	1.16	2.98	2.49	1.09	1.11	4.01	1.81	1.23	1.34
FeO	6.47	5.65	7.77	4.91	2.69	7.37	....	4.49	2.19	3.25
MgO	2.33	.78	.78	.61	.35	5.21	.13	1.05	.73	.26
CaO	6.17	3.36	4.05	3.17	3.06	3.10	2.47	3.16	2.30	2.20
Na_2O	3.81	5.31	3.68	3.09	5.06	2.21	5.27	3.32	4.36	3.50
K_2O	3.06	4.14	3.90	4.25	5.15	3.63	5.04	4.08	5.66	5.90
H_2O	.57	.52	.49	.41	.30	.93	.30	.35	.77	.40
TiO_2	.19	.....	.....	.....	.07	.....	.....	1.00	.....	.....
P_2O_5	.88	.....	.....	.....	.....	.25	.....	.40	.....	.03
MnO	.35	.09	.08	.....	trace	.....	.....	.17	.07	.10
S	.14	.....	.....	.....	.....	.12	.....	.04	.....	.....
Cl	.....	.....	.....	.....	.....	.....	.....	.02	.....	.....
F	.05	.....	.....	.....	.....	.....	.....	.03	.....	.....
BaO	.10	.....	.....	.....	.13	.....	.....	.03	.....	.05
ZrO	.....	.....	.....	.....	.....	.....	.....	trace	.....	.....
CO_2	.....	.....	.....	.....	.....	.58	.....	.....	.....	.....
	100.19	100.23	100.10	100.09	99.73	99.49	99.71	100.39	100.18	100.22

I. Basic syenite from near Raquette Falls. E. W. Morley, analyst. Described by H. P. Cushing: New York State Museum Bulletin 115, pages 513-514.

II. Augite syenite. Line of townships 22 and 23, Franklin County. E. W. Morley, analyst. Described by H. P. Cushing: New York State Museum Bulletin 115, page 514.

III. Augite syenite, 3½ miles north of Tupper Lake Junction. E. W. Morley, analyst. Described by H. P. Cushing: New York State Museum Bulletin 115, pages 514-516.

IV. Augite syenite, Ticonderoga. Essex County. M. K. Adams, analyst. Described by J. F. Kemp: New York State Museum Bulletin 138, pages 45-46.

V. Augite syenite (akerite), Loon Lake, Franklin County. E. W. Morley, analyst. Described by H. P. Cushing: Bulletin of the Geological Society of America, volume 10, 1899, pages 177-192.

VI. Syenite, Whitehall, New York. W. F. Hillebrand, analyst. Described by J. F. Kemp: New York State Museum Bulletin 138, pages 45-46.

VII. Augite syenite (akerite) from Diana, New York. Description and analysis by C. H. Smyth, Jr.: Bulletin of the Geological Society of America, volume 6, 1895, pages 271-274.

VIII. Quartz-hornblende syenite, one mile northwest of Northville. E. W. Morley, analyst. Described by W. J. Miller: New York State Museum Bulletin 153, pages 14-17.

IX. Augite syenite, Little Falls, New York. E. W. Morley, analyst. Described by H. P. Cushing: New York State Museum Bulletin 115, pages 514-515, 518.

X. Quartz syenite, 2½ miles south of Willis Pond, Altamont, Franklin County. E. W. Morley, analyst. Described by H. P. Cushing: New York State Museum Bulletin 115, pages 514-519.

By consulting the table of analyses above of the Adirondack syenites and comparing them with analyses of the Blue Ridge type in table on page 202, it will be seen that in general variation in chemical composition is almost as great for the Virginia type as for the Adirondack type. This variation gains added confirmation when the norms and positions of the rocks in the quantitative system are computed from the analyses. The two types show about equal range in silica, but the Adirondack syenites are richer in alumina and total alkalies than the Virginia rock.

It is from the mineralogical composition gained from microscopic study of thin sections of the rocks from the Adirondacks and the Blue Ridge that the differences become most apparent. The distinguishing features of the Adirondack syenites are: (1) The feldspars, which make up 50 to 80 per cent of the rock, are microperthitic orthoclase and soda-rich plagioclase, the ratio of orthoclase to plagioclase being variable; and (2) the most prominent mafic mineral is green augite, with sometimes a little hypersthene, hornblende being very common and frequently more abun-

Normative Feldspar Composition of Syenite from the Adirondacks, New York, and the Blue Ridge, Virginia

	Adirondacks, New York									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Orthoclase	18.13	24.40	23.02	25.58	30.0	21.13	29.47	24.46	33.42	34.81
Albite	32.17	44.85	31.13	26.20	37.2	18.34	44.54	27.77	36.84	29.61
Anorthite	21.43	17.04	13.89	15.85	9.7	18.34	7.51	11.40	7.78	6.92
Total plagioclase	53.60	61.89	45.02	42.05	46.9	26.68	52.05	39.17	44.62	36.53
Total feldspar	71.73	86.29	68.04	67.63	76.9	47.81	81.52	63.63	78.04	71.34
Ab_nAn_m ratio	1.4:1	2.6:1	2.2:1	1.6:1	3.8:1	2.2:1	5.9:1	2.4:1	4.7:1	4.3:1
Orthoclase-plagioclase ratio	1:2.9	1:2.5	1:1.9	1:1.6	1:1.5	1:1.2	1:1.9	1:1.6	1:1.3	1:1.4

	Blue Ridge, Virginia				
	XI	XII	XIII	XIV	XV
Orthoclase	21.68	25.02	22.24	7.78	22.80
Albite	28.82	20.44	20.44	37.20	23.58
Anorthite	15.57	15.29	13.34	10.29	18.35
Total plagioclase	44.39	35.73	33.78	47.49	41.93
Total feldspar	66.07	60.75	56.02	55.27	64.73
Ab_nAn_m ratio	1.8:1	1.3:1	1.5:1	3.6:1	1.2:1
Orthoclase-plagioclase ratio	1:2	1:1.4	1:1.5	1:6.1	1:1.8

I to X.—Corresponds to analyses on page 214.
XI to XV.—Corresponds to analyses on page 202.

dant than augite in the more quartzose facies, and biotite rare. The Blue Ridge type is more closely allied with rocks of dioritic than of syenitic composition because of its chief feldspar being a more calcic plagioclase of andesine composition, although orthoclase is a prominent constituent and in some thin sections may equal or exceed plagioclase in amount. Broadly speaking, the rock is more a transitional than a well defined type. For convenience of comparison the composition and ratios of the normative feldspathic content of the Adirondack and Blue Ridge types are given in tabular form on the preceding page.

Summarizing the results obtained from a comparison of the normative feldspathic constituent of the syenite from the Adirondacks and the Blue Ridge, the Adirondack type shows a higher average of total feldspar (71.29 per cent as against 60.57 per cent for the Blue Ridge), a higher average total of plagioclase (44.85 per cent as against 40.66 per cent for the Blue Ridge), a higher average total of orthoclase (26.44 per cent as against 19.90 per cent for the Blue Ridge), and a more nearly equal ratio between total orthoclase and total plagioclase (1:1.6 as against 1:2 for the Blue Ridge). Not only does normative orthoclase average higher in the Adirondack type, but normative plagioclase is more sodic than in the Blue Ridge type. This is confirmed both by the examination of thin sections of the rocks under the microscope and by chemical analysis. The above statements are based on averages of the total analyses. Examination of the table will indicate wide variation in each case, and individual analyses may be singled out which show reasonably close agreement for the rocks from the two States.

Quartz is subject to a wide but about equal variation in both the Adirondack and the Blue Ridge type, and unquestionably specimens from the Adirondacks can be duplicated in the Blue Ridge, so far as the amount of quartz is concerned.

In the Adirondack type the chief mafic constituent is augite, with hornblende very common, and at times a little hypersthene, but rarely biotite. The Blue Ridge type is a hypersthenic rock with constant augite, which in places may even equal or exceed in amount hypersthene. Hornblende is less common and biotite rare, except in one or two places, where it becomes an important constituent. The ratio of mafic to felsic minerals is naturally variable, but probably no more so for the Adirondack type than for the Blue Ridge type. Wide variation in both normative hypersthene and diopside characterizes the rocks from both regions, but the average for each is quite close for the same type in the two States, although the norms of the Virginia type apparently indicate a slightly higher average in each.

In conclusion, it may be stated that while certain striking differences are apparent in the type from the Adirondacks and the Blue Ridge, yet there are equally as strong resemblances, and the Blue Ridge rocks discussed in this paper seem to be more closely similar to those of the Adirondacks than of any similar large area in this country.

COMPARISON WITH CHARNOCKITE [29]

The charnockite series of southern India includes a group of Archean hypersthene rocks which range in composition from granite to pyroxenite, the members being so related as to constitute a distinct petrographic province. The more siliceous varieties, though rare, are pyroxene diorites and hypersthene granites (77.47 per cent SiO_2), and the more mafic ones are norites (50.04 per cent SiO_2) and pyroxenites (46.86 per cent SiO_2). However, the most abundant representative of the series is a rock of intermediate composition containing about 63.77 per cent SiO_2. It is characterized by abundant andesine with orthoclase, often perthitically intergrown, with hypersthene, and blue and gray quartz. Augite, hornblende, and biotite occur, the first two being remarkably uniform in character in all occurrences of the charnockite series and are almost as characteristic as hypersthene.

Analyses of Rocks of the Charnockite Series [30]

(H. S. Washington, analyst)

	I	II	III	IV
SiO_2	77.47	63.85	50.04	47.44
Al_2O_3	11.00	14.87	11.65	5.36
Fe_2O_3	1.04	2.32	2.63	3.13
FeO	2.02	5.07	15.76	12.42
MgO	0.43	3.29	5.58	19.96
CaO	1.02	4.48	7.89	7.60
Na_2O	2.86	3.72	3.08	0.48
K_2O	4.14	1.09	0.89	0.10
H_2O+	0.20	0.11	0.19	0.08
H_2O-	0.05	.....	.....	
TiO_2	0.26	0.83	1.93	1.29
ZrO_2	.....	trace	.....	none
P_2O_5	none	0.08	0.20	0.27
S	.....	0.15	.....	0.34
Cr_2O_3	.....	none	.....	0.07

[29] T. H. Holland: Memoirs Geol. Survey of India, vol. xxviii, part 2, pp. 119-249; Quart. Jour. Geol. Soc. London, vol. 53, 1897, p. 405.

[30] We wish to express to Dr. H. S. Washington our sincere appreciation for his kindness in granting us permission to use the four complete analyses recently made by him of rocks belonging to the charnockite series, for which grateful acknowledgment is made.

	I	II	III	IV
MnO	none	0.05	.....	0.15
BaO	.....	none	.....	none
SrO	.....	0.04	.....	.....
	100.59	99.95	99.64	100.69

I. Hypersthene granite, Saint Thomas Mount, Madras, India.
II. Hypersthene quartz diorite, Yercaud, Shevaroy Hills, Madras, India.
III. Norite, Saint Thomas Mount, Madras, India.
IV. Hornblende hypersthenite, Pammal Hill, Pallavaram, Madras, India.

Norms corresponding to the Analyses of Rocks of the Charnockite Series on page 218

(Calculated by Dr. H. S. Washington)

	I	II	III	IV
Q	41.22	20.95	.....	.....
Or	24.46	6.67	5.00	0.56
Ab	24.10	31.44	26.20	4.19
An	5.00	20.57	15.29	12.23
Di	.....	1.36	19.43	18.97
Hy	3.34	13.74	20.27	42.35
Ol	.....	.....	5.63	13.01
Mt	1.62	3.25	3.71	4.41
Il	0.61	1.52	3.65	2.43
Ap	.....	.....	0.34	0.67

Classification

Number.	Symbol.	Magmatic name.
I	I. 3′. ′2. 3.	tehamose
II	II. 4. 3. 4′.	tonalose
III	III. 5. 3. 4′.	camptonose
IV	IV′. 1′. ′2. 1. 2.	hilose

There appears to be remarkably close correspondence in mineral composition of the most abundant variety of charnockite of intermediate composition and the Blue Ridge, Virginia, syenite. The principal minerals, andesine with orthoclase and hypersthene, and the nearly constant presence of augite are identical in the two types. In the charnockite the silica percentage is about 63.77, and in the Blue Ridge type an average of five analyses (page 202) gives 63.89 per cent silica. Hornblende seems to be more constantly present in the charnockite series, while both types are alike in the irregular occurrence of biotite.

Feldspar intergrowths are not so characteristic of the Blue Ridge type as of the charnockite member, but are equally characteristic of the feldspar members of the Nelson-Amherst counties, Virginia, comagmatic area,

which forms a part of the larger Blue Ridge petrographic province. Similarity is again shown to the larger Blue Ridge province in the quartz of the quartz-bearing members being either of blue or gray color.

Again, the members of the charnockite series vary in composition from granites to pyroxenites with a similar variation shown in the Blue Ridge series, and in each province the rocks are hypersthenic. It must be stated here, however, that while there is apparently a close correspondence in mineral composition and in the variety of types in the two provinces, the field relations of the several types to each other in the Blue Ridge province are not yet conclusively determined.

Unakite Type

ORIGIN OF NAME

The name unakite was first applied by Bradley[31] in 1874 to "a member" of the granitic series from the Great Smoky Mountains, a portion of the Unaka Range of the Blue Ridge, which range forms the boundary between North Carolina and Tennessee." Bradley's description was based on specimens seen from the slopes of the peaks known as "The Bluff," "Walnut Mountain," and "Max's Patch," Cocke County, Tennessee, and Madison County, North Carolina. His brief description of the rock (unakite) is as follows:

"The character relied on for the separation of the species is the constant replacement of the mica of common granite or the hornblende of syenite by epidote. The amount of this ingredient present is quite variable, in some cases even exceeding one-half of the whole mass. The feldspar present is orthoclase of various shades of pink, forming from one-fourth to one-third of the whole. The quartz is mainly white, but occasionally smoky; its isolated portions form but a small part, say one-fourth of the mass; it is veined in structure, but this is probably not a constant character. Small grains of magnetite are scattered through the rock, but not so thickly as in many granites. No other ingredients have as yet been detected. Mr. G. W. Hawes has determined the specific gravity at 2.79."

DISTRIBUTION AND CHARACTERISTICS OF UNAKITE

Since the publication of Bradley's original note on unakite, in 1874, occurrences of the rock have been noted and described from a number of localities in Virginia and North Carolina.[32] The rock is by no means

[31] F. H. Bradley: Amer. Jour. Sci., 3d ser., vol. vii, 1874, pp. 519-520.

[32] W. C. Phalen: Smithsonian Miscellaneous Collections, vol. 45, 1904, pp. 306-316.
Thomas L. Watson: Jour. Geol., vol. xii, 1904, pp. 395-398.
Watson, Laney, and Merrill: North Carolina Geol. Survey, 1906, pp. 172-174.
Thomas L. Watson: Amer. Jour. Sci., vol. xxii, 1906, p. 248.
Thomas L. Watson: Bull. 426, U. S. Geol. Survey, 1910, pp. 22, 71, 73, 77-78, 111-112, 157-159.

restricted in distribution to the localities published, as the writers have noted its occurrence in many places in the Blue Ridge of Virginia in association with the type (hypersthene-orthoclase-bearing quartz diorite) described above. In the many occurrences noted the rock shows considerable variation, both in color and in composition. Usually two phases are recognized: (1) A highly feldspathic phase in which pink or red feldspar amounts to three-fourths of the mass, the other two essential constituents being yellow green epidote and white to smoky quartz; and (2) a non-feldspathic phase composed of quartz and epidote and designated epidosite. Feldspar is not apparent in hand specimens of the epidosite phase of the rock, but is recognized microscopically in some thin sections. Other variations are into essentially all quartz on the one hand and into essentially all epidote on the other. All gradations between the two principal phases of the rock mentioned above are noted.

The rock is low in quartz, but contains much epidote. The feldspar is usually orthoclase or microcline, or both. Plagioclase is rare in the thin sections studied, and mafic minerals have not been identified. From its mode of occurrence and association in the thin sections studied, epidote is clearly a secondary mineral. Its microscopic description by the senior writer in the unakite of Madison County, North Carolina, is essentially similar to that of the Blue Ridge, Virginia, occurrences and is quoted in full.[33]

"It [epidote] occurs in large masses composed of minute microscopic granules, many of them replacing the entire feldspar individuals, and as continuous and irregular disconnected bands and areas of large and small size, following the fractures in both the feldspar and the quartz, but most extensively developed in the feldspar. The development of epidote along the breakage lines can be continuously traced in many places from the larger areas or masses replacing the entire feldspar individuals across or into contiguous feldspars. In still other places the feldspar shows scattered granules of epidote over its surface. All gradations between these two extremes of epidotization appear. Hardly any of the feldspar in the sections examined was entirely free from some epidotization."

The commonest accessory minerals are zircon, apatite, and iron oxide.

A chemical analysis of the unakite from Milams Gap, in the northern Blue Ridge of Virginia, gave the following result:

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[33] Thomas L. Watson: Bull. 426, U. S. Geol. Survey, 1910, pp. 158-159; see also Jour. Geol., vol. xii, 1904, p. 397.

Analysis of Unakite, Milams Gap, Virginia

(W. C. Phalen, analyst)

	Per cent
SiO_2	58.32
Al_2O_3	15.77[34]
Fe_2O_3	6.56
FeO	.89
MgO	.09
CaO	11.68
Na_2O	.32
K_2O	4.01
H_2O	1.73
P_2O_5	.48
MnO	.13
ZrO_2	trace
	99.98

ORIGIN OF THE UNAKITE

The unakite-bearing rock of the Unaka Mountains of western North Carolina and eastern Tennessee is a coarse biotite granite varying from porphyritic to even-granular in texture, usually exhibiting pronounced secondary gneissoid structure, and mapped by Keith[35] as the Max Patch granite of Precambrian age. In the Blue Ridge of Virginia the unakite-bearing rock, where observed, is a quartz-bearing hypersthene-andesine syenite, previously described by Phalen[36] in the Milams Gap locality as hypersthene akerite. In each instance it seems entirely clear that the unakite and its associated rock are derived from the same magma, and all who have studied the unakite from the several localities are in agreement that epidote, one of the essential minerals, is secondary in origin; also that the epidote has developed from feldspar and the mafic constituents (biotite in the North Carolina-Tennessee area, and pyroxene and to some extent hornblende in the Virginia area) through chiefly hydrometamorphism (action of percolating meteoric waters), aided probably by dynamic metamorphism.

Only certain very restricted parts of the rock of either State are unakite-bearing. From the senior writer's studies of the Madison County, North Carolina, area it seemed quite conclusive, from the different exposures studied of the unakite in its relations to the epidote-bearing granite, that it was of distinct vein character, which can be referred very likely to the segregation type. It is suggested, then, that in some cases

[34] Includes TiO_2.

[35] Arthur Keith: Asheville Folio (No. 116), Geol. Atlas U. S., U. S. Geol. Survey, 1904.

[36] W. C. Phalen: Op. cit.

at least the now highly epidotized portions of rock yielding the type unakite represent magmatic segregations or secretions similar to schlieren or possibly pegmatite, some of whose original constituents have been altered to epidote chiefly by hydrometamorphism.

ZIRCONIFEROUS EPIDOSITE

In the syenite areas north of James River fragments of highly epidotized rock occur, many of which are rich in ilmenite, apatite, and zircon. The rock is found in largest quantity on the southeast slope of the Blue Ridge in the Beverly Settlement in Amherst County. The rock was not found in place, but the loose fragments were associated with those of syenite in such fashion as to suggest its probable occurrence as possible segregations in the syenite. It certainly seems possible that it has a similar genesis to that of the probable related type, unakite. In hand specimens of the rock the minerals easily recognized are, named in order of abundance, epidote, quartz, ilmenite, zircon, and apatite. Epidote and quartz compose the bulk of the rock, with the former greatly in excess. The ilmenite, zircon, and apatite are not distributed uniformly through the rock, but are grouped in close association with each other in irregular areas. Each of these minerals varies greatly in amount in the different hand specimens.

Zircon occurs in small crystals of light reddish-brown color (colorless in thin sections), and at least 50 were removed from a single small specimen of the rock. The largest crystal measured 2.5 millimeters in length and 1 millimeter in thickness.

Microscopic study of thin sections gave no additional information from that gained by megascopic study of hand specimens as to the character of the rock.

Granite

Field investigation of many of the syenite areas in the Blue Ridge discloses the association of more acidic rocks of granitic composition in which quartz usually becomes very abundant. Orthoclase (microcline) is increased in amount and the plagioclase constituent is more sodic. Mafic minerals are decreased in amount and in some instances they fail almost entirely. Like the syenite, the weathered portions of the granite show characteristic pitted surfaces. The pitting from weathering and disappearance chiefly of the feldspar has left the quartz in projecting reticulated areas in the more massive phases of the rock and in more or less drawn out connecting spindles in the more gneissic phases.

The exact field relations of the granite and syenite have not been defi-

nitely determined for all areas, but in several the evidence seems conclusive to the writers for regarding them as differentiation phases of the same intrusive magma, since definite contacts between the two types have nowhere been observed; but on the contrary there seems to be a gradual passage from one into the other. In several of the areas on the southeast slope of the middle Blue Ridge that have been studied in most detail it is possible to collect specimens along a traverse that will range in the amount of quartz from a minimum in the more typical syenite to a maximum in normal granite, with practically all gradations between the two extremes. It is regretted there are no available analyses of the more acid type of rock of granitic composition. For such areas the field relationships and microscopic study of thin sections are best explained on the assumption that the granite is an acid extreme of the syenite. So far as our studies have extended, we have not been able to note any border phenomena in either rock of the several areas where the two are associated which would indicate that one has been cut by the other. However, detailed field studies have not been extended to all known areas of the rocks, and to say that such relations do not exist would be unwarranted at the present stage of our knowledge. In some places the granite occupies areas up to several miles in width in which apparently no syenite appears, while in other places a traverse will show alternations of granite and syenite. The former relation is especially true of the granites mapped and described by Keith[37] in the northern Blue Ridge of Virginia.

The granites are even-granular, medium-grained rocks of fairly uniform texture, of light gray or pink color, and usually show indistinct to pronounced foliation developed from pressure metamorphism. In hand specimens feldspar and quartz are easily distinguished, the latter being of bluish color in some cases. Considerable green epidote is developed in places, especially in the pink granite, yielding a rock similar in appearance and composition to unakite (pages 220-223). Garnet is sparingly developed and is largely altered to chlorite.

Microscopic study of thin sections of the granites shows them to be, in part at least, pyroxenic rocks. In most thin sections examined complete alteration of the original ferromagnesian constituents to epidote, chlorite or amphibole, and iron oxide rendered their determination impossible. Cores of orthorhombic pyroxene rimmed by secondary fibrous amphibole and iron oxide as alteration products were observed in a few thin sections of the light gray granite. No trace of an original ferromagnesian mineral was noted in any thin section of the pink granite. Whatever dark

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[37] **Arthur Keith: Fourteenth Ann. Rept. U. S. Geol. Survey, part ii, 1892-1893, pp. 285-395.**

silicates were present in the rocks originally could not have been abundant because of the present small amounts of secondary minerals that could have been derived from them.

The most abundant constituent of the rock is feldspar, which is chiefly orthoclase and microcline, and always some sodic plagioclase (albite-oligoclase) in varying amount, almost equaling in a few thin sections the potash varieties. Much of the orthoclase is intergrown with albite as microperthite, but graphic intergrowths with quartz are rare. Quartz is next to feldspar in importance and is of the usual kind in granites. The common accessory minerals are the same as those observed in the syenite which comprise magnetite, apatite, and zircon. Others sometimes noted are needle-like inclusions of rutile in some of the quartz, garnet in irregular masses, and crystals frequently partially or completely altered to chlorite and epidote.

Norite

GENERAL DISCUSSION OF CHARACTERISTICS AND DISTRIBUTION

Gabbros have thus far been observed by the writers only at several localities in the Blue Ridge region of Virginia in association with the pyroxene syenite. In each instance the rock is hypersthenic, and is therefore a norite. So far as our field investigations have extended, two varieties of the norite have been studied, the most abundant one of which is a hornblende norite (analysis III, page 229), the other a variety abnormally rich in apatite and ilmenite (analysis I, page 229) and closely resembling in this respect the gabbro-nelsonite[38] (roselandose) of the high titanium-phosphorus rocks of the Amherst-Nelson counties comagmatic area near the southeastern foot of the Blue Ridge. Both varieties are rich in hypersthene and diallage (see analysis II, page 229, and map, page 195). Analyses of these two varieties of gabbro (I and III) are given in the table of analyses on page 229, with which are compared analyses of gabbro and gabbro-nelsonite of the Amherst-Nelson counties area[39] (II,

[38] Nelsonite, a new rock type, is the name that was given by Watson to a group of high titanium-phosphorus-bearing rocks of igneous origin, occurring in dikelike bodies of varying size and irregular shape in the Amherst-Nelson counties region, Virginia, and to a less extent farther southwest on the northwest slope of the Blue Ridge in Roanoke County. The name gabbro-nelsonite, a new rock type, was proposed by Watson and Taber for a holocrystalline igneous rock having a mineralogical composition intermediate between normal gabbro and nelsonite proper. The nelsonites proper belong to class V of perfemanes, but occupy new rang and subrang positions in the quantitative system, and accordingly are new rock types to which appropriate magmatic names have been given. See T. L. Watson: Mineral resources of Virginia, 1907, p. 300; Watson and Taber: Bull. 430, U. S. Geol. Survey, part i, 1909, pp. 200-213; University of Virginia publications, Bull. Phil. Soc., scientific section, vol. 1, 1913, No. 14, pp. 331-333; Bull. III-A, Virginia Geol. Survey, 1913, pp. 100-155.

[39] Watson and Taber: Bull. III-A, Virginia Geol. Survey, 1913, pp. 138-145.

IV, and V) and of norites from Maryland (VI) and the Adirondacks (VII and VIII).

The area that has been studied in greatest detail in the Blue Ridge proper lies north of James River Gap, on the two slopes of the Blue Ridge in Amherst and Rockbridge counties. Other areas that have been studied and published on are the Amherst-Nelson counties comagmatic area[40] near the southeast foot of the Blue Ridge and the Hemlock area[41] in Floyd County, southwest Virginia. The gabbro of the Floyd County area is a pyrrhotite-rich hornblende norite containing biotite and a little olivine.

Several areas of gabbroic rocks of the hornblendic variety have been studied in the Robinson Gap section, about 8 miles northeast of Balcony Falls. One of the areas is located in Rockbridge County, on the northwest slope of the Blue Ridge; the others occur in Amherst County, on the southeast slope of the ridge. The principal body of gabbro is found in the Beverly Settlement, in Amherst County. It is essentially a hornblende norite, although a biotite facies occurs, but is not abundant. The smaller areas of gabbroic rocks are described below, under pyroxenite. The gabbroic rocks, including pyroxenite, and the syenite are intimately associated, but the evidence is not yet conclusive as to what are their exact field relations. Small bodies of the syenite are found in the larger gabbro mass, while similar bodies of pyroxenite are associated with the gabbro, from which they differ chiefly in the presence of scant feldspar and the substitution of biotite for hornblende. Smaller areas of pyroxenite are distributed as dikelike bodies in the syenite and may represent either independent intrusions as dikes or segregations as schlieren in the syenite body. That the rocks are differentiates from a common magma is entirely evident on mineralogical and chemical relationships, but whether they represent separate intrusions or variants from differentiation in place can not be definitely answered at this time. Further detailed investigations of this igneous complex in the region immediately to the north will be necessary before this question can be settled. In general the chief difference noted in the gabbros and the more abundantly associated type syenite is in the proportion and not in the kind of minerals, for the important constituents in one type are usually present in greater or less quantity in the other.

MEGASCOPIC CHARACTER

For the areas studied the gabbroic rocks are of dark gray to nearly black color and of medium, even-granular texture. They show distinct

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[40] Watson and Taber: Bull. III-A, Virginia Geol. Survey, 1913, pp. 42-234.

[41] T. L. Watson: Trans. Amer. Inst. Mng. Engrs., vol. xxxviii, 1907, pp. 683-697.

foliation (gneissic) in places, but frequently they appear entirely massive in structure. In the more highly feldspathic facies of the rock (gabbro proper) the light and dark colored minerals are so distributed with reference to each other as to impart a decidedly speckled appearance to the rock. Variation in the proportion of the light and dark minerals is observed, but as a rule the dark ones are in excess.

The recognizable minerals in hand specimens of the gabbro are pyroxene, hornblende, feldspar, and sometimes biotite. In the Floyd County rock sulphides range up to 50 per cent of the total rock-mass. Pyroxene is more abundant than hornblende, the latter mineral apparently failing in some specimens. A distinct diallage parting may frequently be seen in specimens with the aid of a pocket lens. Like the syenite and granite types previously described, the weathered surfaces of the gabbro show pitting from the removal of pyroxene and feldspar, leaving hornblende and some of the lesser more resistant minerals standing in relief.

MICROSCOPIC DESCRIPTION

Study of thin sections of the gabbro under the microscope shows the principal minerals to be diallage, hornblende, hypersthene, occasional biotite, and calcic plagioclase. Minor constituents are quartz, apatite, titanite, magnetite, and sulphides (pyrite and pyrrhotite). Pyroxene, as augite (diallage) and hypersthene, the former usually in excess, is the most important constituent. It is developed in stout allotriomorphic grains, containing the common platy forms of brown inclusions, which are more abundant in the augite than in the hypersthene, and, in addition, inclusions of the minor constituents. The augite is usually very fresh, but hypersthene is partially or completely altered, the manner of alteration being identical with that of the syenite, yielding a fibrous pale green amphibole, accompanied by the separation of iron oxide in extreme cases, and frequently considerable calcite.

The feldspar is completely altered in all thin-sections of the hornblende gabbro studied, but from the character of the alteration products it is inferred that probably two varieties are present. Kaolin is the most frequent alteration product of the feldspathic constituent, with which is associated some muscovite. A reasonably fresh specimen of the biotite-rich gabbro (pyroxenite) studied contained but little feldspar, the principal variety of which was andesine-labradorite, showing well developed albite and sometimes pericline twinning. An appreciable amount of orthoclase and some quartz were present.

Hornblende is an important mineral of the rock, but is not so abundant as pyroxene and is not so uniformly distributed. The optical properties

indicate that it is near common hornblende in composition; the angle $c \wedge z$ is about 23 degrees; absorption is $z =$ deep brown, x and y light brown. It shows no alteration.

ILMENITE-APATITE GABBRO

This type was not found in place, but is represented by abundant large and small boulders littering the surface on the southeast slope of Rocky Row Mountain between James River and the headwaters of Rocky Row Run, in Amherst County. It is not possible, therefore, to say what its field relations are to the other rocks. The rock is very dark in color because of the predominance of ilmenite and pyroxene, although feldspar irregularly distributed through the rock is recognized, usually grouped in irregular-shaped areas of about 1 inch in diameter. Apatite is developed in small crystals, many of which show hexagonal outline; when crystal form is lacking the mineral is distinguished with difficulty from the small grains of secondary epidote. Some secondary quartz, red garnet, and chlorite can be distinguished in hand specimens. Indistinct foliation is developed in the rock.

Microscopic study of thin sections of the rock show it to be much altered, the most abundant minerals of which are secondary, including chlorite, amphibole, epidote, and quartz. However, in some thin-sections the original minerals are sufficiently fresh to determine the composition of the rock to be chiefly hypersthene, plagioclase (labradorite), some orthoclase, ilmenite, apatite, diallage, and quartz.

Hypersthene is abundant, but is much altered, the alteration being identical with that of the hypersthene in the syenite, with the exception that considerable chlorite is developed in the alteration of the gabbro. Diallage is less abundant than hypersthene and does not occur in all thin-sections; but when present it is fairly fresh, with only slight alteration to probably amphibole along the cleavage and fractures. Plagioclase of the variety labradorite is greatly altered, and in most cases little or none of the original mineral remains. Some orthoclase is also present.

The richness of the rock in apatite and ilmenite is a noteworthy feature, which removes it from the ordinary gabbro, and in this respect the rock resembles the gabbro-nelsonite (roselandose) of the Amherst-Nelson counties area,[42] an analysis of which is given on page 229. The apatite is in large amount in all thin sections studied, developed both as separate large rounded hypidiomorphic crystals and as small crystals inclosed in the other minerals. It varies in quantity in different thin-sections and

[42] Watson and Taber: Bull. III-A, Virginia Geol. Survey, 1913, pp. 138-142.

even in parts of a single section, but it is remarkably fresh. Ilmenite is developed in scattered irregular granular masses of large sizes, partially altered to leucoxene. Both primary and secondary quartz occur containing abundant inclusions of rutile needles. Original hornblende was not identified in any thin section of the rock.

CHEMICAL COMPOSITION AND CLASSIFICATION

The composition of the Blue Ridge gabbros described above is shown in analyses I and III of the subjoined table. III shows no unusual features in composition, but I is especially interesting because of its unusual richness in TiO_2 and P_2O_5. It is compared with the analysis (II) of the new rock type gabbro-nelsonite of the near-by Amherst-Nelson comagmatic area. The two rocks are rich, but not equally so in TiO_2 and P_2O_5. In most other respects the two rocks are chemically unlike, as indicated not only by the analyses, but by their positions in the quantitative system, I being a salfemane and II a dofemane. Mineralogically, however, the two are closely similar, since they contain the same silicate and ore minerals, but in different proportions.

For purposes of comparison, analyses of hypersthene gabbros (norites) from several well known eastern areas are introduced in the table—IV and V from the Amherst-Nelson, Virginia, area; VI from the Baltimore, Maryland, area, and VII and VIII from the Adirondack region. Disregarding the gabbro-nelsonite represented by analysis II, the rocks show decidedly close chemical relationships, as indicated by their positions in the quantitative system. They are all salfemanes and fall into order 4 or 5, rang 3 or 4, and subrang 3 or 4.

Analyses of Gabbros

	I	II[43]	III	IV	V	VI	VII	VIII
SiO_2	42.10	33.83	47.67	50.99	51.08	46.85	47.16	44.77
Al_2O_3	12.06	5.19	15.93	12.40	16.45	19.75	14.45	12.46
Fe_2O_3	1.10	11.38	1.96	2.10	.84	3.22	1.61	4.63
FeO	8.43	15.08	6.80	11.80	10.08	7.99	13.81	12.99
MgO	5.62	8.57	8.99	4.09	6.95	7.75	5.24	5.34
CaO	8.63	8.22	12.32	6.46	5.57	13.10	8.13	10.20
Na_2O	1.97	1.28	1.68	2.38	3.49	1.56	3.09	2.47
K_2O	1.12	.50	.79	2.19	1.28	.09	1.20	.95
H_2O-	.20	.45	.12	.12	.08	.56	.12	.12
H_2O+	3.80	.75	1.80	1.21	.51		.48	.48
TiO_2	10.15	4.84	.85	4.66	4.44	.....	3.37	5.26
P_2O_5	3.77	10.00	.13	1.86	.14	.....	.57	.28
MnO	.63	.26	1.51	.11	.08	.....	.24	.17

[43] Contains Cl— .04, F— .55.

	I	II	III	IV	V	VI	VII	VIII
NiO, CoO	none	trace	none	trace	trace	.....	.02	.37
CO_2							.35	
S	none	.25	.16	trace	trace	.....	.14	.26
	99.58	101.39	100.71	100.37	100.99	100.84	99.98	100.75
Excess O		.30						
		101.09						

I. Apatite-ilmenite gabbro (norite) from southeast slope of Rocky Row Mountain, about 3 miles north of James River, Amherst County, Virginia. J. G. Dinwiddie, analyst.

II. Gabbro-nelsonite exposed on the west side of the Arrington-Roseland Road, 1 mile south of Roseland. Type locality. William M. Thornton, Jr., analyst. Watson and Taber: Bulletin III-A, Virginia Geological Survey, 1913, pages 138-142, especially page 140.

III. Hornblende gabbro (norite) from the southeast slope of the Blue Ridge in Robinsons Gap, Amherst County, Virginia. J. G. Dinwiddie, analyst.

IV. Gabbro (norite) dike exposed on 100-foot level, 50 feet from shaft, General Electric Company's mine, 1.5 miles northwest of Roses Mill. William M. Thornton, Jr., analyst. Bulletin III-A, Virginia Geological Survey, 1913, page 95.

V. Gabbro (norite) in Roseland-Arrington Road, near Mr. Adams' house, about 100 yards south of Roseland post-office. William M. Thornton, Jr., analyst. Bulletin III-A, Virginia Geological Survey, 1913, page 95.

VI. Gabbro (norite), Baltimore, Maryland, area. Average of 23 typical specimens. L. McKay, analyst. G. H. Williams: Bulletin 28, United States Geological Survey, 1886, page 39.

VII. Gabbro, Woolen Mill, 1 mile west of Elizabethtown, Essex County, New York. W. F. Hillebrand, analyst. J. F. Kemp: Bulletin 138, New York State Museum, 1910, page 40.

VIII. Gabbro (norite). Wall rock of titaniferous magnetite deposit, Lincoln Pond, Essex County, New York. George Steiger, analyst. J. F. Kemp: Nineteenth Annual Report of the United States Geological Survey, part iii, 1899, page 407.

Norms of Gabbros corresponding to Analyses on page 229

	I[44]	II	III[44]	IV	V	VI[44]	VII[44]	VIII[44]
Q	8.94	7.38	.....	8.94	.....	.....	.....	.....
Or	6.67	2.78	4.45	12.79	7.23	.06	7.2	5.6
Ab	16.77	11.00	14.15	19.91	29.34	13.01	26.2	21.0
An	20.57	6.95	33.64	16.68	25.58	43.9	25.0	19.5
Di	.....	1.51	21.57	3.43	.92	17.3	12.5	25.9
Hy	14.10	22.55	9.87	21.05	27.53	11.4	8.1	4.0
Ol	.....	.....	9.42	.....	.....	8.4	12.8	5.9
Mt	.....	16.47	2.78	3.02	1.16	4.6	2.3	6.7
Il	19.30	19.15	1.67	8.82	8.36	.....	6.4	9.9
Hm	1.12	.....	.....	.....	.....	.....	.....	.....
Ap	9.07	11.42	.34	4.03	.31	.....	1.3	.....

[44] Norms calculated by Dr. H. S. Washington.

Summary of Classification

Number.	Symbol.	Name.
I	III. 4'. (3)4. 4.	no name
II	IV.$_{II}$3. 1. 2. 3.	roselandose
III	III. 5. 4. 4.	auvergnose
IV	'III. 4'. 3. '4.	vaalose
V	'III. 5. 3'. 4.	andose-camptonose
VI	III. 5. 4. 3.	auvergnose
VII	III. 5. 3. 4.	camptonose
VIII	III. 5. 3. 4.	camptonose

Pyroxenite

DISTRIBUTION

The several small areas of gabbroic rocks referred to under gabbro are here classed as pyroxenite. The areas are in the same general region, but are rather widely separated. One occurs in Rockbridge County near the northwest slope of the Blue Ridge, about 3 miles southeast of Buena Vista; the other occurs in Amherst County, on the southeast slope of the Blue Ridge, on the Robinson Gap Road, three-quarters of a mile southeast of the church in the Beverly Settlement.

MICROSCOPIC CHARACTER

In mineral composition the rock can not be considered a typical representative of either the gabbro or the pyroxenite group, but must be regarded as a transitional or intermediate type, as confirmed by the analyses on page 232. In some respects it is more closely allied with the gabbros than with the pyroxenites, but because of its being essentially a pyroxene aggregate with considerable biotite and subordinate feldspar it has seemed best to group it with the pyroxenites. The rock is the same in the several areas studied and differs essentially from the gabbro of the same district in containing less feldspar and hornblende, but increased amounts of augite (diallage), hypersthene, and biotite. Because of the great preponderance of the dark-colored mafic minerals, the pyroxenite is much darker in color (nearly black) than the normal gabbro.

Microscopic study of thin sections indicated the same optical properties of the minerals as for those in the gabbro described above. Augite (diallage) is in excess of hypersthene and some original quartz and orthoclase occur. Biotite is more abundant than hornblende, the latter failing entirely in several thin sections. Because of the presence of some feldspar and much biotite, the rock is designated a biotite-feldspar-bearing pyroxenite.

CHEMICAL COMPOSITION AND CLASSIFICATION

A chemical analysis of the biotite-feldspar-bearing pyroxenite from the northwest slope of the Blue Ridge in Rockbridge County is given in column I below. Analyses of two other well known pyroxenites—one from Baltimore County, Maryland (II), and one from Webster, North Carolina (III)—are tabulated for comparison. I is a feldspar-biotite-bearing hypersthene-diallage mixture, II a bronzite-diopside aggregate, and III is a bronzite-diallage mixture. Thus on the basis of mineral composition each of the rocks represents a different type of pyroxenite, a difference clearly expressed chemically in the analyses below. In the Virginia rock (analysis I) the presence of feldspar manifests itself in the increased percentages of alumina, lime, and alkalies. The greater richness of the Maryland (II) and the North Carolina (III) rocks in the enstatite molecule (bronzite, which is hypersthene in the Virginia rock) accounts for the greatly increased percentage of magnesia, which is about double that of the Virginia rock.

The difference in composition of the three rocks is further shown in the table of norms below. As indicated by their positions in the quantitative system, the Virginia rock is a dofemane, while the Maryland and North Carolina rocks are perfemanes.

Analyses of Pyroxenite

	I	II	III
SiO_2	50.08	50.80	55.14
Al_2O_3	6.56	3.40	.66
Fe_2O_3	1.56	1.39	3.48
FeO	8.94	8.11	4.73
MgO	12.95	22.77	26.66
CaO	16.14	12.31	8.39
Na_2O	.89	trace	.30
K_2O	.46	trace	none
H_2O-	.19	.52	.38
H_2O+	.32		
TiO_2	1.90	none	trace
P_2O_5	.19	trace	.23
MnO	.40	.17	.03
Cr_2O_3	.....	.32	.25
Cl	.....	.24	.....
S	.37	trace	.....
	100.95	100.03	100.25

I. Biotite-feldspar-bearing pyroxenite from northwest slope of the Blue Ridge in Robinsons Gap, Rockbridge County, Virginia. J. G. Dinwiddie, analyst.

II. Pyroxenite, Johnny Cake Road, Baltimore County, Maryland. J. E. Whitfield, analyst. G. H. Williams: American Geologist, volume vi, 1890, page 41.

III. Websterite, Webster, North Carolina. E. A. Schneider, analyst. G. H. Williams: American Geologist, volume vi, 1890, page 44; also Bulletin 148, United States Geological Survey, 1897, page 92.

Norms[45] *of Pyroxenites corresponding to Analyses on page* 232

	I	II	III
Q	.....	.....	1.7
Or	2.78	.....	.....
Ab	7.34	.....	2.6
An	12.51	9.2	.....
Di	53.60	41.4	32.7
Hy	13.10	33.8	57.1
Ol	4.48	12.2	.....
Mt	2.32	2.1	5.1
Il	3.65	.....	.....
Ap	.34	.....	.....

Summary of Classification

Number.	Symbol.	Name.
I	IV. 1'. 1'. 2(3). 2.	no name
II	V. 1. 1. 2. 2.	baltimorose
III	V. 1. 1. 2. 1.	websterose

Age Relations

In the northern Blue Ridge of Virginia the syenite traced at irregular intervals along the west side of the mountains southward from Dickeys Hill, in Warren County, is found in more or less intimate association with the Catoctin schist of Algonkian age. The Catoctin is a dark-colored, dense, and heavy basaltic rock, two varieties of which have been recognized by Keith,[46] a lower diabasic sheet and an upper basaltic sheet, both altered, sometimes highly schistose, with the upper one largely epidotized. In his discussion and mapping of the igneous rocks in this part of the Blue Ridge, Keith[47] has clearly shown that all are Precambrian, and that the sequence of events involves the granite intrusion [including syenite] between the diabase eruptive and the diabase flow.

Farther south, in the middle Blue Ridge region, the basal conglomerates of the Lower Cambrian series contain frequent well-rounded pebbles of the pyroxene syenite on which the sediments rest. The evidence is con-

[45] Calculated by Dr. H. S. Washington.

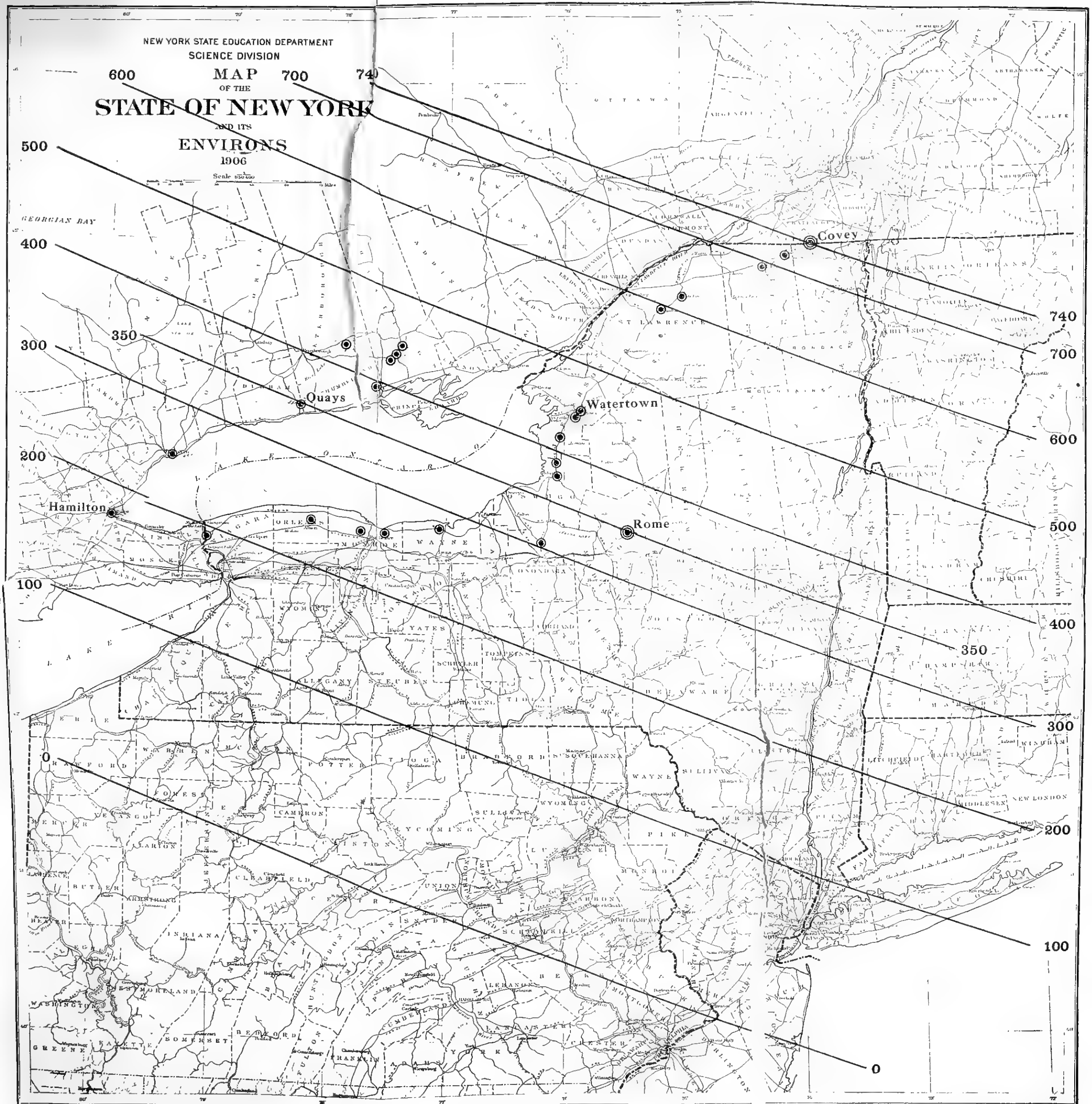
[46] Arthur Keith: Fourteenth Ann. Rept., U. S. Geol. Survey, part ii, 1892-1893, pp. 285-395.

[47] Arthur Keith: Ibid., pp. 296-318.

clusive, therefore, that the syenite of this region at least is Precambrian in age. The same evidence applies to the granites, which in this region, as in the northern Blue Ridge, are Precambrian.

Where observed by us, the syenites of the Blue Ridge indicate, from their relations to other rocks, Precambrian age; but whether more than a single period of intrusion is represented can not be answered from our present knowledge of the field relations. It has been shown that the syenite has not been equally metamorphosed in all places, but that the rock varies greatly in structure from massive to highly gneissic, and sometimes almost schistose. The principle of inequality of metamorphism alone, as expressed in the rock structures of this region, can not be used as a positive criterion for regarding the rocks to be of more than one period of intrusion, and therefore of different age, since in some areas there can be traced syenite of the same mass whose structure ranges from massive or only faintly gneissoid to highly gneissic, which is beyond question the product of a single intrusion. On the other hand, there are areas where such evidence is apparently lacking, and there may have been more than a single period of intrusion of the syenite.

It has been pointed out that the syenite shows variations in some localities into more acid or granitic phases on the one hand and possibly into more basic or gabbroic phases on the other, though the evidence is much less conclusive for the latter. Not until the region has been covered by thorough detailed study can the field relations of the several rock types be finally settled, and whether there has been more than one period of intrusion of the syenite magma. It can be stated in conclusion, however, that the relations show conclusively that the syenite of at least some of the areas, and probably of all, is of Precambrian age.



H. L. Fairchild, 1915

PLEISTOCENE UPLIFT OF NEW YORK STATE

The lines of equal uplift (isobases) show the total amount of deformation. The isobases are inclined 20 degrees from the latitude parallels and represent straight lines on the earth surface. The imaginary surface connecting the isobases is the upraised and deformed marine plane of the close of glacial time. The circles are stations used in the tabulated data, plate 11.

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PLEISTOCENE UPLIFT OF NEW YORK AND ADJACENT TERRITORY [1]

BY HERMAN L. FAIRCHILD

(Read before the Society December 29, 1915)

CONTENTS

General Statement

In 1913 the writer published (see number 127 of the bibliography) evidence and argument to prove the deep submergence of the Connecticut and Hudson-Champlain valleys and indicated by a map the approximate amount of postglacial uplift. It was shown that the marine plane, represented by a wealth of shore phenomena, rises from zero below New York City to over 700 feet on the Canadian boundary, and that the isobases are inclined 20° from the latitude parallels, running north of west by south of east. In other words, the direction of steepest upslope is north 20° east. The determination of these directions was made by connecting points of equal altitude on the marine plane in the Hudson and the Connecticut valleys, and with no regard to any previous work or writing on land deformation. It is significant, therefore, to note that Professor Coleman found the direction of greatest uplift of the Iroquois plane in

[1] Manuscript received by the Secretary of the Society January 7, 1916.

the Ontario basin to be 20° east of north (95), and that Professor Goldthwait estimated the post-Algonquin deformation of the Great Lakes area as north 22° east (109). The practical agreement of the conclusions of three independent students, covering overlapping areas, although perhaps somewhat different time episodes, is evidence of accuracy that may be accepted in our court of last resort.

The writer's study of the Iroquois and marine planes in the Ontario-Saint Lawrence area has been handicapped by lack of topographic maps and precise altitudes. Recently an advance sheet of the Chateaugay quadrangle made possible the precise mapping of the Iroquois and Gilbert Gulf shores on the west side of the northern salient. We now know with fair precision the altitudes on both sides of the Covey Hill promontory. Here the Iroquois beach ends, while the marine beach follows around the salient, running northwest from the Champlain Valley into Canada, and then southwest back into New York past the villages of Chateaugay and Malone.

The important fact is determined, which seemed theoretically probable, that the land deformation and hence the isobasal lines of the Saint Lawrence-Ontario area are in accord with those of the Champlain-Hudson and western New England. The Adirondack mass and the wide surrounding areas seem to have upraised in unity when the total uplift of both glacial and postglacial time is considered. It appears that the land warping during the successive episodes of the ice removal had somewhat different directions in the several provinces of the large area, but the combined effect has produced a fair regularity of slope over the entire area. This is shown by the map (plate 10).

If the low altitude of the land at the close of glaciation had any causal relation to the weight of the ice-cap then it would seem to logically follow that no uplifting occurred until the ice-body was waning and the glacial load diminished. This implies that the ice-front had receded from its most advanced position before land uplift began, and it appears quite certain from facts to follow that the land uplift at *any* point was subsequent to the removal of the glacier at that point. It follows, therefore, that the summit features of the marine shorelines in the Hudson and Connecticut valleys register the total Pleistocene uplift in those areas; and the same must be true of the deep valleys of New England that lie open to the sea.

It also appears certain that the Hudson and Connecticut valleys could not rise independently of the regions east and west, except by great and conspicuous faulting. It seems theoretically proper to extend the isobasal lines of equal uplift westward across the whole of New York State and

eastward into New England. The observational data and the calculated results confirm the theoretic unity of the larger territory.

As the Labradorian glacier reached only to Staten Island, the ice-front recession through the Hudson-Champlain Valley represents all the time involved in the removal of the ice-sheet, not only from all of New York, but from most or all of the Great Lakes area. The recession to Albany corresponds in time to the recession from Salamanca to Syracuse. The stages in the melting of the ice-sheet from New York have been shown in a series of maps published by the New York State Museum (119, plates 32-40; 125, plates 9-17). We have in the Hudson-Champlain Valley a direct, complete, and evident record of the total amount of land uplift during Pleistocene time for all of New York and the region of the Great Lakes. Conversely, it is the record of the depth of submergence in the sea at the close of glacial time.

Outside the sea-flooded area the record is not so clear or full. In the Erie and Ontario basins the tilted shorelines of the glacial lakes, when compared and their deformations added, give us approximate figures. The latest continuous beach of any particular lake registers only the deformation subsequent to the extinction of the lake. The uplifting which occurred during the life of the water body may be suggested by the shifting of outlets or by the splitting of beaches; but these records are not always clear and they may be overlooked. Any possible uplift before the initiation of the lake will, of course, not be recorded in its beaches.

However, if the land uplift in any particular district was subsequent to the un-icing of that locality, the glacial lakes which laved the receding glacier front evidently register the earliest rising of the land. Many years ago, in 1891, Mr. Upham made calculations, based on the several glacial lake shorelines in the Erie and Ontario basins, with remarkably accurate results (27, pages 261-262). This subject will be discussed later.

Isobases

The accompanying map, plate 10, shows in isobasal lines the *total* uplift of the land in Pleistocene time. Conversely, it shows the depression when beneath the load of the Labradorian ice-cap.

If the reader refers to the map and diagram in the former article (127, plates 10, 11), a difference will be noted between those maps and present map which needs explanation. In the former diagram (plate 10) the line representing the tilted uplift was drawn as a straight line, to be used as a datum plane, in the absence at that time of sufficient data to plot the line with its true curvature. In the sketch map (plate 11) the iso-

bases were located in harmony with the datum plane and consequently were equally spaced.

It must be understood that the "hinge line" can not be a true line, but is a belt of country; or, in other words, the hinge is flexible and not a joint. The stationary or non-tilted surface must gradually blend into the uplifted area. In different expression, the tilted surface must slowly flatten out into the undisturbed area. This implies that the gradient, or rate of uplift, increases toward the north for some distance and must be drawn as a curving line. The isobases of lower value, from zero up, will be spaced further apart than those in the area of steeper tilting. In the present map the isobases are placed as accurately as the data permit, and it is believed that they are approximately correct. The isobases of 200 to 400 feet uplift are located at practically the same points as in the former map. The zero and 100-feet lines are carried southward, while those above 400 feet, in the region of steeper tilt, are more closely spaced, which carries them also to the south.

The amount of Pleistocene submergence and subsequent uplift indicated on the present map for New York City district and also for the Champlain Valley are slightly more than in the former map.

The isobases are drawn with inclination from the latitude parallels of 20°, 70° divergence from the meridians, which give them a curvature equal to their nearest parallels, on the projection of the map. Further knowledge and extension of the isobasal lines over larger territory, specially eastward, may require some slight changes in position and spacing, and specially in curvature; for somewhere, both west and east, the lines must bend into sharper curves to lie about the center of maximum uplift.

The positions of the isobases of 200 to 500 feet were determined by comparison of marine summit phenomena in the Hudson and Connecticut valleys. The 100-feet line is located with special reference to the deformation in the Lake Erie basin. Leverett gives the amount of deformation of the Maumee beach at the Ohio-Pennsylvania boundary as 10 feet (100, page 739). At this point the later and lower Whittlesey beach has an altitude of 746 feet (100, page 756). A rise of 90 feet more, or to 836 feet, evidently gives the total uplift of 100 feet. This point on the Whittlesey shoreline is found about 9 miles east of Dunkirk and 2 miles north of Forestville and about 4 miles south of Silver Creek. This point, therefore, is taken for the location of the isobase of 100 feet. Drawn approximately parallel to the 200-feet isobase, it crosses the north boundary of New Jersey and intercepts the Hudson River 3 or 4 miles south of Tarrytown. Precise measurements of the marine plane in the lower Hudson will check this line. But in passing it may be noted that

Professor Salisbury says (97, page 203): "On the whole, the evidence seems to favor the conclusion that the northwestern part of the State (New Jersey) was covered by standing water to the depth of 100 feet or more after the ice retreated, though this conclusion can not be regarded as beyond question. If this be correct, the area has risen a corresponding amount since the ice melted." And F. J. H. Merrill gives the amount of uplift at New York City as 80 feet, and at Peekskill as 120 feet (63, page 105), which accords with the map altitudes. In giving Croton Point as 100 feet, which is about 15 feet too low to harmonize with his other altitudes, he only made the common error of accepting the broad, conspicuous delta plains as the summit level.

The zero isobase is drawn parallel with the 100-feet line so as to touch Ashtabula, Ohio, which point is given by Leverett as the locality where the Maumee and Whittlesey beaches lose horizontality (100, pages 755-756). This position for the zero line accords precisely with Goldthwait's limit of horizontality of the early beaches in the Michigan Valley (108, page 465). These locations of the zero and 100-feet isobases, based on well-determined beach altitudes, gives the increased spacing required by theory.

In the Whittlesey and Warren shorelines we have yet other checks, on higher altitudes farther north. Using Leverett's figures as far as Marilla, we find that the total uplift at that locality is 164 feet. As the isobases lie on the map, Marilla is estimated as between 162 and 165 feet. Pond triangulation station, 8 miles northwest of Batavia, is the highest point on the Warren beach, with altitude 887 feet (118, page 77). This is 32 feet higher than the same beach on the Marilla isobase, which gives us 196 feet for the uplift at Pond; and the point is just over the 200-feet isobase. When the several variable factors are considered, the correspondence of the isobases on the map with the field data is remarkably close.

The only question which can be raised as to the validity of the isobases on the Hudson-Champlain meridian is whether they indicate the whole amount of Pleistocene uplift. They have been determined by study of the abundant shore phenomena practically continuous along both sides of the Hudson-Champlain and Connecticut valleys, and therefore they can not represent too great depression and uplift. The objection to the sea-level character of the waters has been on account of the deep submergence which the beaches imply.

If the isobases do not represent the total land movement, it must be because some rising occurred in areas covered by the glacier, so that the

waters were excluded; and this raises the isostatic problem, the rate and manner of uplift during the waning of the ice-cap.

No one is likely to hold the view that a large continental area would rise indifferent to the ice-load, or that the northward differential uplift occurred beneath the ice-body, for that would imply that the ice-burdened area rose faster than the unloaded region. The causal relation of the glacier to the land movement seems to be well grounded in geophysical philosophy.

The alternative to such conception is that of a wave uplift responsive to the unloading. We can not postulate a small or local uplift immediately at or beneath the edge of the ice-sheet. Some considerable depth of the earth's crust is involved, and time is required to establish the elastic reaction and isostatic movement and the flow of the deep-seated material. The uplift wave must be dilatory. If the earth wave of uplift ever overtook the receding glacier margin, the amount of rise there must have been very small as compared with the subsequent uplifting.

All the facts from field study and all the philosophy based on them (largely suggested in the tabulated data, plate 11) lead to the conception of a wave uplift subsequent to the removal of the ice. The isobases almost certainly represent the total land uplift and will be so regarded in this paper.

Marine Plane

In the northern edge of the State the most critical locality is the Covey pass, the second outlet of Lake Iroquois. The summit marine level is there 740 feet. On either side of the salient, of which Covey Hill is the point, heavy gravel bars are found in close set series. On the east these stretch for miles south and north of Cannon Corners, in the northeast corner of the Mooers quadrangle. Woodworth saw and mapped part of these bars (103, map), but did not correlate them. The highest of these splendid cobble bars are about 4 miles southeast of Covey outlet and about a mile north of Cannon Corners, by the White school, with altitude 735 feet. On the west side of the promontory a fine display of cobble bars lies about 6 miles northeast of Chateaugay village, in the extreme northeast corner of the Chateaugay quadrangle, and three-fourths of a mile north of the Irish school and one-fourth mile south of the International Boundary monument, No. 706A. The summit altitude of this series has not been determined with great precision, but it is 730 to 735 feet. As bars, cliffs, or deltas, the marine shore is strongly developed in the Chateaugay district. It passes into Canada just west of Frontier and follows the land slope northeast, past the west end of the Covey outlet channel.

This shoreline of sealevel waters has been mapped at various points in the Saint Lawrence Valley. In the Ontario basin and upper Saint Lawrence it is represented by the Gilbert Gulf beaches, described in 1905 (117). The summit features of the marine shore are now traced in practical continuity the whole length of both sides of the Hudson-Champlain Valley, about the Covey Hill salient, and through the Saint Lawrence-Ontario Valley until they pass beneath the waters of Lake Ontario near Oswego (117, page 714). The remarkable series of heavy gravel bars which lie at 525 feet above Covey Hill salient, passing near Covey Hill Post-Office, and through Maritana and Franklin Center, reentering New York at Boyds Lines, represents a relative pause in the rising of the land. This beach series is over 200 feet below the summit plane of the sealevel waters. West of Plattsburg this lower beach series disappears, while the Cannon Corners, the summit series, is remarkably heavy, and is represented by shore phenomena the whole length of the Champlain-Hudson Valley, on both sides. On the north face of Covey Hill the summit marine plane is poorly represented, for the reason that the upper slope had been swept bare by the heavy ice-border drainage of the down-draining Iroquois, so that little material was left on the slope for the construction of bars, and because the work of the waves and currents on the salient was erosional and not constructional.

The Cannon Corners beaches are on extensive tracts of cobble delta which were built in the sealevel waters by the latest outflow, around Covey Hill, of the lowering Iroquois waters. This stretch of delta lies along the east edge of a broad belt of bare Potsdam sandstone, the "Stafford" and "Blackman" rocks, which were swept clean by the stream-flow. The relation of the lowest distributary channels on these deltas to the cobble beaches helps to determine the altitude of the standing water, which is taken as 740 feet at the Covey channel. Because of the critical relation of the marine plane to the latest level of Iroquois an isobase of 740 feet is drawn through the Covey outlet. The isobases of 600 and 700 feet are given theoretical positions, but in good accordance with abundant data on both the New York and Vermont sides of the Champlain Valley.[2]

No attempt is made to locate the 800-feet isobase, but this may be done after examination of the marine summit in the north edge of Vermont. It seems certain that the sealevel waters passed over the top of Mount Royal, at Montreal.

[2] The detailed descriptions and mapping of the marine and Iroquois phenomena will be given in publications of the New York State Museum and the Vermont Geological Survey.

It is possible that the gradient of the warped surface may decrease north of New York, and that in the Champlain Valley we have the steepest portion of the upslope. Precise determination of the summit features in the north edge of Vermont, New Hampshire, Maine, and eastward will throw light on this problem. For several reasons which may not be discussed here, the inscriptions left by the highest waters may be very weak and difficult to trace, but the common mistake should be avoided of regarding the upper conspicuous features as necessarily the summit level.

Iroquois Plane

In the Hudson-Champlain Valley the marine plane is shown by the isobases, but not in the Saint Lawrence and Ontario basin. In the south part of the latter area considerable rise occurred before the sealevel waters were admitted. The isobases in this area represent not only the later uplift out of the sealevel waters, but also the rise during the previous episode, the life of Lake Iroquois. In the relation of the Iroquois to the marine level is found the key to very interesting facts.

As far north as the Watertown district the Iroquois shore has long been known, being traced and measured by Spencer (43) and Gilbert (36) and in later years by the writer (114). In recent years Chadwick and the writer have located Iroquois beaches at several points to the northeast, and we now have approximate altitudes of the shoreline clear to Covey hollow, the second and final outlet of the ancient lake. The Chateaugay and Churubusco sheets of the topographic maps cover the last 20 miles of the shoreline in New York, while the remaining 3 miles lie in Canada, covered by the Chateaugay sheet of the Canadian government. Very definite features are found close to the boundary line, at 1,025 feet, and the water surface at Covey outlet is regarded as 1,030 feet.

The relation in altitude of the two outlets of Iroquois, Rome and Covey, was very close, if not practically identical. If the waters under control by the Rome outlet reached the Covey Pass decidedly higher than the latter, we should expect some record of river flow on the south slope of the pass, but such has not been found. Moreover, in such case a drop in the water level should be recorded in the beaches of the lake shore; but the beach along the south shore and west end of the basin is a unit and seems to have been formed in rising water. It is barely possible that the control of the earliest flow through the Covey Pass was not at the pass, but around on the east side of the highland, in the region of the Altona bare rocks. It is probable that the Covey Valley originally held some filling of glacial drift which the Iroquois outflow had to remove in

order to establish the channel as we find it. For reasons that will appear later in this writing, it seems quite certain that there was no appreciable land uplift in the Covey district, while the Covey outlet was effective; but any considerable rise would have thrown the outflow back on the Rome outlet. These questions are subjects for future intensive study. But even now it seems clear that there could not have been great difference between the altitudes of the two outlets, and that the highest beach south of the Rome isobase and the latest beach in all the basin correlates with the Covey outlet and practically with the Rome outlet also. When the former is described and illustrated, it will be seen that it carried the pre-Saint Lawrence flood long enough to establish its shoreline.

The Covey outflow persisted while the front of the glacier rested against the north and east faces of Covey Hill at a height above 1,030 feet. While the ice-front was receding, on the north-facing slope, from 1,030 down to 740 feet, the sub-Iroquois outflow was scouring the slope between those altitudes. In horizontal distance on the northeast face of Covey Hill the drop from 1,030 to 740 feet is only about one-half mile. How long time did this bit of ice-front recession consume? And how much uplift of the district occurred during this episode? Relatively, the time must have been brief, and if there was any rising of the land at all it was so small that we may consider it negligible in our calculations.

Altitudes and Warping in the Ontario Basin

It is believed that the time interval between the abandonment of the Covey outlet and the establishment of the marine level in the Ontario basin was relatively so short that the land uplift at Covey outlet during that brief time is negligible as compared with the total uplift. With this admission, it follows that the vertical interval everywhere in the Ontario-Saint Lawrence depression between the Iroquois and the marine planes is 290 feet (1,030 minus 740). This uniform interval throughout the basin provides us with a master key to the amount of deformation during two time episodes—Glacial (Iroquois) time and post-Glacial (post-Iroquois) time. Wherever in the Lake Iroquois area we can find the altitude of either the Iroquois or the marine plane, we can calculate the other one. The marine or sealevel altitude in the Ontario basin represents the amount of post-Iroquois uplift. By subtracting this from the total uplift, as indicated in the map of isobases, we determine, for that point in space, the amount of uplift previous to the extinction of Iroquois, which is Glacial time for New York; and the total uplift, the isobasal value, subtracted from the present altitude of the point, gives us the height of that point above the ocean before the uplifting began.

The table, plate 11, gives examples of the above analysis. Comparison of this table with the map of isobases brings out clearly some very interesting and important data. It appears that Hamilton, Ontario, at the extreme west end of Lake Iroquois, received during Glacial time more than half of its total uplift. The same is true of Rome, the southeastern extremity of the lake and the main outlet; and these two points, Rome and Hamilton, were the first to be relieved of the ice burden. At Lewiston the glacial uplift was just half the total, while between Lewiston and Rome, the most southerly stretch of the Iroquois shore, but somewhat longer beneath the ice load than the east and west points, the glacial uplift was less than the post-Iroquois rise. It will be seen that Rome was the point of largest Glacial uplift and of the lowest initial altitude. From Rome northward the Glacial uplift was small, declining to zero near the Canadian boundary, where all the rise seems to have taken place after the marine level was established in the Saint Lawrence Valley.

These figures appear to prove that the New York area did not rise as a rigid body, but that the uplifting was a wavelike movement, following the removal of the waning ice-sheet, as long ago suggested by Upham (31).

The low initial attitude of Rome agrees with the requirement for the early glacial drainage, for the earliest ice-border streams in central New York passed east to the Mohawk-Hudson by channels at Syracuse which today, after uplifting and Iroquois silting, are less than 400 feet above tide (115, 119). The Schenectady-Albany district was beneath the sea down to much later time, though some uplift occurred in Iroquois time, as proved by directions of Iromohawk flow beyond Schenectady, described by J. H. Stoller (112).

The tabulated data studied in connection with the map shows that different portions of the large area had different up-movements. About the east end of the Ontario basin the post-Iroquois uplift was steepest in a northerly direction, due to the later and more rapid rise of the Canadian area. This partly accounts for the steep gradient on the Iroquois shore north of the fulcral line.

In applying the mathematics of the table to any particular locality it must be understood that the figures apply to the particular point taken for Iroquois or for marine altitude; for example, the figures for Hamilton, Ontario, are for the summit of the Iroquois bar. The initial altitude of the city of Hamilton would be calculated by comparison of its altitude with the summit of the great gravel ridge of Iroquois. Rome is a more complex example. The altitude taken is the crests of the beaches southwest of the city—460 feet. The lowest part of the col or wasteweir of

Canada Localities.	Hamilton.	Toronto.	Quays.	Trenton.	Oak Hill.	Havelock.	Madoc.	West Huntingdon.
Present altitude of Iroquois	**362**	**434**	**557**	**632**	**676**	**682**	**696**	**738**
Extinction altitude of Iroquois	290	290	290	290	290	290	290	290
Post-Iroquois uplift.. / Present marine plane	72	144	267	342	386	392	406	448
Glacial uplift, before Iroquois extinction	98	106	83	53	39	33	24	2
Total uplift, by isobases	170	250	350	395	425	425	430	450
Rise of Iroquois level due to flooding	82	74	Splitting of beaches. **0**	**55**	**36**	?	**25**	**6**
Initial altitude	110	110	207	237	251	257	266	288
Present altitude of Iroquois	**362**	**434**	**557**	**632**	**676**	**682**	**696**	**738**

New York Localities	Hamilton, Ontario.	Lewiston.	E. Gaines.	Greece.	Rochester (W. Webster).	Sodus.	Woodward.	Rome.	Richland.	Lacona.	Adams.	Brookside.	Watertown (Farrs).	Russell.	Canton (isobase).	Potsdam, Parishville.	Malone.	Chateaugay.	Covey.
Present altitude of Iroquois	**362**	**385**	**430**	**440**	**440**	**456**	**452**	**460**	**544**	**565**	**603**	**650**	**671**	?	860	**900**	**980**	**1,015**	**1,030**
Extinction altitude of Iroquois	290	290	290	290	290	290	290	290	290	**290**	**290**	**290**	**290**	?	**290**	**290**	**290**	**290**	**290**
Post-Iroquois uplift.. / Present marine plane	72	95	140	150	150	166	162	170	254	**275**	**313**	**360**	**381**	?	**570**	**610**	**690**	**725**	**740**
Glacial uplift, before Iroquois extinction	98	95	105	110	110	114	143	180	121	115	102	85	69	?	25	10	5	**0**	**0**
Total uplift, by isobases	170	190	245	250	260	280	305	350	375	390	415	445	450	?	595	620	695	**725**	**740**
Rise of Iroquois level due to flooding	82	85	75	80	70	66	37	Splitting of beaches. **0**	**22**	**38**	**42**	**51**	**62**	**35**	?	?	?	**0**	**0**
Initial altitude	110	110	110	110	110	110	110	110	169	172	188	205	221	?	265	280	285	**290**	**290**
Present altitude of Iroquois	**362**	**385**	**430**	**440**	**440**	**456**	**452**	**460**	**544**	**565**	**603**	**650**	**671**	?	**860**	**900**	**980**	**1,015**	**1,030**

PLEISTOCENE DEFORMATION OF THE ONTARIO BASIN

Altitude figures refer to ocean level. The figures in heavy face are field measurements

the ancient stream head is about 430 feet. Hence the initial altitude of that point would be 110 feet minus 30, or 80 feet. But this must not be regarded as the height of the divide and channel head in pre-Iroquois time, for it is quite certain that the Rome district has been buried under delta filling by the glacial drainage from the north (125), and that the original land surface was much below 80 feet altitude. It is thought that the earliest control of glacial stream-flow was at Little Falls, 36 miles southeast of Rome.

Three classes of figures in the table are derived figures—those for the two periods of land uplift and those for the amount of flooding by Iroquois waters. These are all based on (1) the fixed vertical interval between the Iroquois and Gilbert Gulf planes and (2) the isobases of total uplift, taken in multiples of 5 feet. The first of these basic elements can not be seriously changed, and any possible change will affect all stations alike. Any modification of the isobases will change the derived figures locally. However, with all reasonable allowance for errors, the data show striking coherence and unity and close agreement with all present knowledge and philosophy.

Outlet Control—Splitting of Beaches

The altitude of the water surface of Lake Iroquois was controlled by the height of the outlet, which, up to the closing episode, was at Rome. It appears that Rome had the greatest amount of uplift during Iroquois time of any point in the basin and was probably the point that was earliest in an area of rising land. There may be suggestion of detrital or delta filling at the outlet to account for some part of the uplifting at Rome. Heavy glacial drainage from the north poured vast quantity of detritus into the Mohawk Valley between Rome and Little Falls during much of the lifetime of Iroquois. (For discussion of this see 116, page 34; page 38.) It seems probable, however, that the great Glaciomohawk River and its successor, the Iromohawk, were not effectively dammed by the tributary filling to any greater extent than to establish sufficient grade over the filling that perhaps extended to the rock channel at Little Falls. The point of outflow or head of the river flow may have shifted westward, with some increase in height; but to whatever amount the Iroquois plane was raised by choking of the Rome outlet, it simply reduces by that much the 180 feet of glacial lifting at that point without in any way affecting the figures for any other locality. The calculations in the table are based on the water planes, and the cause of changes in the Iroquois level does not modify the consequences of such changes.

In 1902 the writer published a description of the Iroquois beaches extending from Richland to Watertown Center, with maps, profiles, and table (114, pages 106-112). In that stretch of splendid beaches conspicuous from the Rome, Ogdensburg and Watertown Railroad, the gravel bars are spaced through considerable vertical range, up to 50 feet at Watertown Center and to 77 feet at the Farr farm, 3 miles east of Watertown, the point used in the accompanying map and table.

It has been the theory of students of the glacial lakes phenomena that the differential uplift of a basin should produce splitting of the bars by the relative lowering of the water level north of the fulcral line, the isobasal line passing through the outlet. It was expected that the vertical spacing of the Iroquois beaches would increase steadily to the northward. This expectation was not realized. From Richland to Watertown Center, 28 miles by the shore, the bars exhibit no consistent or harmonious relation and no decided increase in vertical range, though the stretch of shore is decidedly tilted as a whole. Four miles farther to the northeast the range at Farrs is 77 feet. From there northward, so far as our detached figures show, the vertical range of bars decreases, and toward the north edge of the State the beach becomes simple.

This discordance with our theories has been something of a puzzle; but now, in the light of the tabulation and the facts of this paper, the explanation seems clear. The Richland-Watertown series of bars registers a local wavelike land uplift just before the extinction of Iroquois and before any recorded rising of the land occurred at Covey outlet. During the life of Iroquois the Rome outlet had been rising and the water level in correspondence. Eventually the ice-body had been so long and so far removed from the upper Saint Lawrence Valley and the Adirondack mass that relatively rapid uplift began in the Watertown district and the land uplift exceeded the rise of the water level by the amount of splitting recorded in the Watertown beaches.

The latest or extinction water level at Farrs is taken as 671 feet, after much study of the matter in the field and office. The summit of the bar series is 733 feet, which makes the amount of splitting of the bars, the uplift out of Iroquois waters, 62 feet. The tabulation gives the glacial uplift at Farrs as 69 feet. When the Covey outlet became effective the rising of the Iroquois water level practically ceased, as that district was not lifted until after the extinction of Iroquois. The stationary attitude of the Iroquois water gave the Watertown wave of land uplift the chance to slowly rise out of the waters and produce the series of beaches.

Between Rome and Richland the Iroquois shore has not been mapped, it lying in a drumlin area, but must be examined with reference to this

question. It is predicted that some splitting of bars, increasing northward, will be found. Between Watertown and Malone precise data have not been sought, but about 12 miles south of Canton, near Russell, Professor Chadwick and the writer measured with aneroid a strong set of Iroquois bars having a vertical range of at least 35 feet.

The figures for Canadian points, from Professor Coleman, show that the glacial uplift declines northward, and the vertical range of bars, as measured in the field, has remarkable agreement with the theoretic derived figures. The Iroquois altitude for West Huntingdon is probably too high.

It should be noted, as an illustration of the wave uplift, that during Glacial time Rome was lifted 111 feet more than Farrs, but that during post-Iroquois time Farrs rose 211 feet more than Rome. This gives Farrs a net excess of 100 feet, the difference shown by the isobases.

In summarizing this topic, it may be said that south of the Rome or fulcral line all the beach phenomena seem to be an effect of rising water; that the splitting of beaches north of the fulcral line declines in amount or vertical range both north and south of Watertown; that the tabulated figures for Canadian points show similar relation, and that the splitting is due to later local land uplift, which probably occurred while the lake outlet was at Covey Pass. This topic is further discussed below.

Flooding of the south Shore of Iroquois

The southern shore of Lake Iroquois has the characters which are produced by a rising water level. The rise of the lake surface was evidently caused by the excessive lifting or differential uplift of the outlet at Rome. Probably the most striking feature produced by the rising water is the huge gravel bar at Hamilton, Ontario. This has been described by Coleman (95, pages 351-352), who implies that the flooding was toward 100 feet. Turning to our table, we find that while Rome was lifted 180 feet, Hamilton was raised only 98 feet, and that consequently that point must have been flooded 82 feet. It is more than mere singular coincidence that 83 feet is the depth in the Hamilton bar at which "unworn Mammoth remains" (95, page 352) were found.

By similar calculation the amount of flooding may be determined at all points. It is estimated that the flooding in the Rochester district was about 70 feet and at Syracuse 45 feet.

To determine the altitude of the initial water surface at any point on the south-shore beaches, we deduct the amount of flooding, plus the amount of total uplift, from the present height of that point. For example, at Hamilton the total uplift, as figured from the isobases of the map, is 170 feet; the flooding is 82 feet. The sum of these deducted

from 362, the present altitude, gives 110 feet. It will be noted that this is the initial altitude of the Iroquois plane at Rome. All points of the flooded area south of the fulcral line will give the same initial altitude, since they are derived figures; but, of course, the original water level was everywhere the same as the outlet.

Checks and Proofs

Several matters already presented in this paper fall properly under this topic, but will not be repeated. There remains, however, a significant coincidence which requires notice.

The direction of the isobases of the map was determined, as stated above, by comparison of the summit features of the marine waters in the Hudson and the Connecticut valleys, and they indicate the total uplift during Pleistocene time. It is an interesting and important fact that Professor Coleman found precisely the same direction for the lines of equal Iroquois uplift in the Ontario basin (95, page 363). Yet the rising movement discussed by Coleman belongs to only the later part of the Pleistocene. Another coincidence is that Coleman drew his fulcral line of the Iroquois uplift through Quays and Rome, which is the precise location of our isobase of 350 feet total uplift. If this is mere accidental coincidence, it is quite remarkable; but if it rests on verities in the sequence of geologic events, it implies a true philosophy.

At first glance the figures of the table show decided lack of harmony. Quays is 557 feet above tide today, while Rome is only 460. While Rome was rising in Glacial time 180 feet, Quays rose only 83 feet; but in post-Iroquois time Quays rose 267 feet to Rome's 170 feet. How is it that these two points, with such diverse uplift figures, can lie on the fulcral line of Iroquois tilting? Evidently they did not for the whole of Iroquois time. By plotting the data in a diagram the solution is suggested. Quays was under the ice-sheet for a long time after Iroquois waters occupied the southern portion of the basin, and during that time no uplift occurred at Quays. When the land finally began to rise at Quays it had already lifted 97 feet at Rome, and the water level stood at 207 feet. From that time onward the two points lifted in comparative unison for 83 feet, or up to 290 feet, the height of Iroquois extinction. Now it should be noted that the table shows that the present uplifted plane of Iroquois started at 110 feet above tide at Rome and 207 feet at Quays.

Again, it may be emphasized that the key to all such calculations is found in the fixed vertical interval between the Iroquois and the marine planes, taken in conjunction with the isobases of total uplift. If either of these elements were wrong, the results would not agree with the facts of observation. Students of the Pleistocene may find other ways of test-

ing these figures. It is believed that the data given in the table harmonize the field data and clarify our knowledge of the Pleistocene water planes in New York, and that further study in the areas not yet mapped will confirm these figures.

One of the most significant proofs of the correctness of the philosophy of this paper is the remarkable coincidence of the derived figures for the amount of Glacial time uplift north of the fulcral line with the actual amount as indicated by the bar spacing found in the field. This is described in the next chapter.

Relation of Land Uplift to the Ice Body

The broad relationship of the Labradorian glacier, in both extent and thickness, to the area and the amount of Pleistocene uplift of the land has long been recognized. The results of the present study, specially shown in the tabulated data, strikingly emphasize the causal relationship of the weight of the ice-body to the land movement.

In the previous chapter it was shown that the two points in the Iroquois area which were earliest relieved of the ice burden, Hamilton and Rome, experienced the largest amount of uplift, relative to the total rise, during Glacial (Iroquois) time, it being more than half. Passing north from Rome, the amount of Glacial uplift decreases rapidly, and at Watertown it is only one-seventh of the total. Farther north it decreases to zero at Chateaugay and Covey outlet. These facts will be used later (see pages 251-252).

The beaches in Canada show similar relations. Toronto, on the same isobase as Greece, with about the same relation to the ice-body, has similar figures, the Glacial uplift being two-fifths of the total. But Quays, on the same isobase as Rome, but much longer under the ice-body, received less than one-fourth of its rise in Glacial time. The district north from Quays shows declining Glacial rise and greater post-Glacial, similar to northern New York. Some of these figures from Professor Coleman are possibly subject to slight correction (95, page 356), but the significant facts will stand.

These facts are all in agreement with our knowledge of the form and mass of the waning ice-sheet during its slow removal from New York. An attempt to exhibit several phases in the ice removal has been made by the writer in a series of maps (119, plates 34-42; 125, plates 9-17).

From the data already in hand it seems certain that the Iroquois basin was not lifted as a rigid mass, but by a wave movement. The south side of the basin was given (on the average) only one-half of its total rise during Iroquois time. The northern portion was lifted very little, and the far north portion not at all, until Gilbert Gulf and later time.

All the phenomena described in this paper and the facts relating to land uplift are explained best on the theory that the rise of the land did not begin in any district until after the ice-sheet was removed from the region, and perhaps far removed. In common with other geologists, the writer has formerly assumed that some land uplift took place beneath at least the border of the waning ice-sheet. This older view requires that a large land area should lift with considerable rigidity quite promptly after the ice load was only partly reduced, or else that a smaller wave movement should follow very quickly.

If the rising of the land surface several hundred feet may be produced only by the inflowage of the interior, plastic magma beneath the area of diminished weight, it must be a very slow process, and we should expect that it would lag far behind the release of pressure; and it would also seem most probable that the uplift would be wavelike instead of the rigid lifting of a large area. It is a question, or balancing, of the relative rate of the melting of the glacier and of the restoration of isostatic equilibrium.

It will be conceded that no uplift would begin in the region of the terminal moraine until release of weight began, which means not until the ice-front had receded; so it is a question if the land uplift will ever overtake the ice-front recession. One might conceive that subsequent to the long time removal of the ice burden from a district some far readvance of the edge of the ice-sheet might lie on rising ground, but such great readvance after the glacial waning was well established and sufficient to produce isostatic uplift seems improbable.

It will not be held that when uplift began it simultaneously involved the entire great area buried under the ice-cap, unless the rising was very dilatory, because the waning of the continental glacier must have been around the borders for a long time before there was any ablation of the ice-cap and reduction of weight over the central area. The only alternative is wave uplift, and the question is, therefore, as to the character of the wave, its breadth, and its time relation to the ice-margin. We have some facts bearing on both elements of the problem.

First, as to the time relation. Certainly the New York City district did not rise at all until the ice was gone, for not until the ice-margin had withdrawn considerable distance was there any effective reduction of weight. Did the wave uplift ever overtake the receding ice-front up the Hudson Valley? All the evidence is negative. In the Schenectady district we have positive proof that the land uplift did not overtake the glacier. For a very long time after the Schenectady-Albany district was under the sealevel waters the Glaciomohawk and Iromohawk rivers were building the great delta with its apex at Schenectady and the spreading flow southeastward. When the uplift finally began the river, blocked by

its own deposits, was diverted northward toward Ballston and Saratoga. The flow in this direction continued for another long episode, sufficient to build the broad sand plains west and south of Saratoga Lake and about Schuylerville. Eventually the differential uplift lifted the Saratoga district faster than the Schenectady district, and the river was thrown back into its present eastward course toward Cahoes.

In the Ontario basin we find interesting and convincing data. The facts shown in the tabulation, plate 11, and already briefly discussed (page 244), clearly indicate that the rise of areas north of the Iroquois fulcral line took place under Iroquois waters and not under the ice-sheet, because in the "splitting of beaches" the vertical spacing of the abandoned bars in Canada and in New York north of Watertown gives a vertical range of lowering water level equal to the whole Glacial uplift before Iroquois extinction; and the amount of glacial uplifting steadily decreases northward instead of increasing, while the latter would have been the case if the land uptilting had been in progress during the recession of the ice-front. This matter is important as a check on our theory. The figures for the spacing of Iroquois bars north of the Rome isobase, the fulcral line, are entirely independent of all the derived figures in the tabulated data. The amount of beach splitting is field measurement already on record in publications. It is the height of the summit bar above the latest and lowest water plane, which is the one used in the analytic tabulation. The close coincidence between the amount of beach splitting and the Glacial uplift in Canada is very significant. Following is the comparison:

	Glacial uplift.	Vertical spacing of bars.
New York points:		
Rome	180	0
Richland	121	22
Lacona	115	38
Adams	102	42
Brookside	85	51
Watertown	69	62
Russell	?	35
Canton	25	?
Potsdam	10	?
Malone	5	?
Chateaugay	0	0
Covey	0	0
Canada points:		
Quays	83	0
Trenton	53	55
Oak Hill	39	36
Havelock	33	?
Madoc	24	25
West Huntingdon	2	6

No way has been found of explaining these figures except by a local wave uplift in the Watertown-Trent River region while under Iroquois waters which were comparatively stationary. If uplift had been in progress while ice lay over the Covey district and Iroquois waters laved the ice-front, then some vertical spacing of the bars would have continued northward to the Covey outlet. Any uplift, even after Covey Pass was opened, would have thrown the outflow back to Rome and still produce splitting of beaches at Covey. The figures appear to prove two things—a wave uplift subsequent to the ice-retreat and the total uplift value of the isobases in the map.

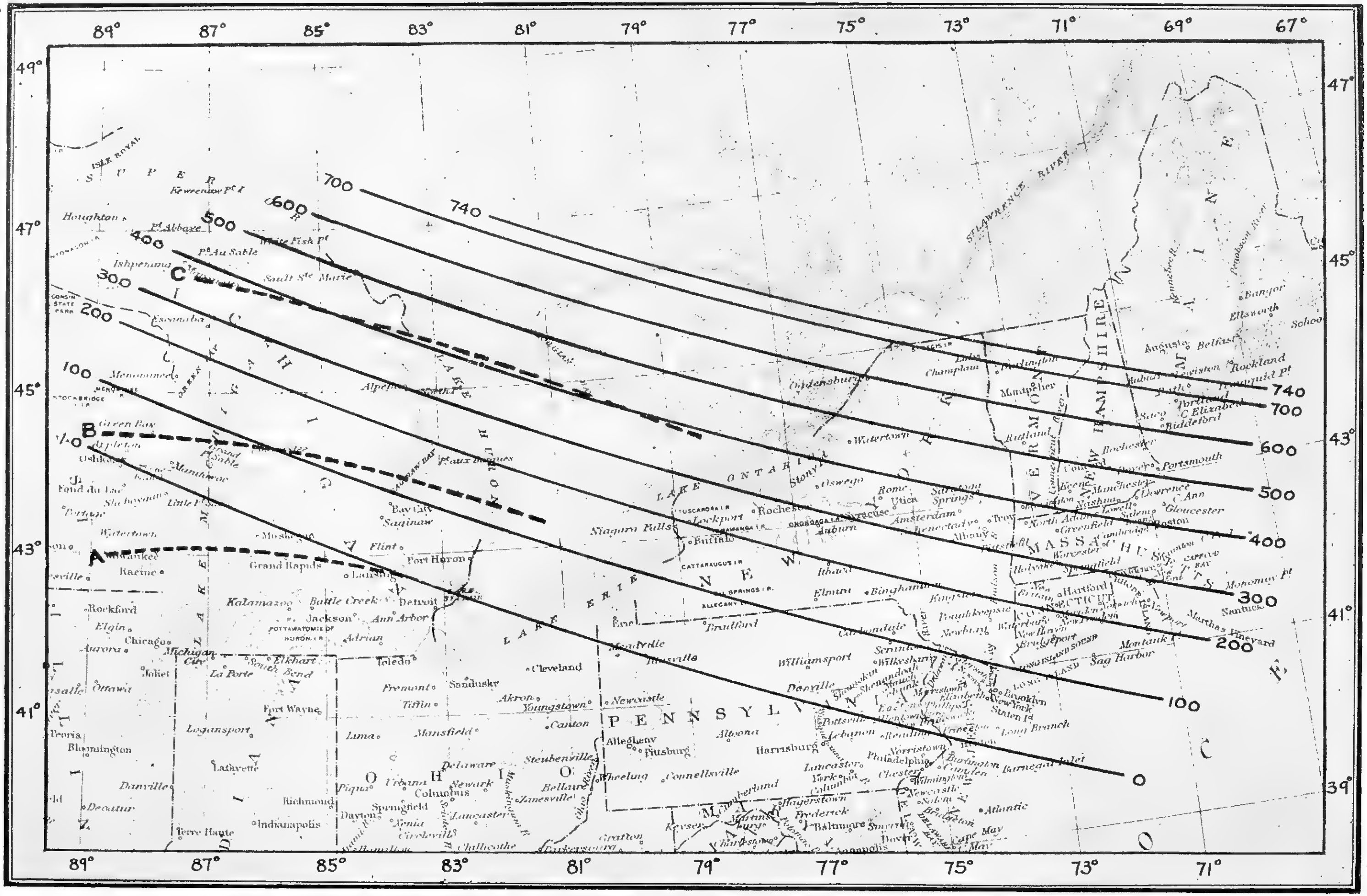
The Canadian points, measured by Professor Coleman, lie in about the same isobasal belt as Watertown and exhibit similar movement, but show less Glacial uplift, evidently because of the longer halt of the glacier over the Ottawa lowland and the belated uplift (125, plate 17). Evidence has already been given to show that Quays did not rise at all until after it was immersed in Iroquois water.

Second, as to the dimensions of the earth wave. While the Watertown district was rising, the Iroquois water level appears to have been comparatively stationary. Any considerable rise at Covey outlet would have thrown the outflow back to Rome, in which case lower bars would have been formed in the Covey district, inferior to the Covey outlet. It appears, therefore, that the district of rapid wave uplift must have been limited by the distance between the two outlets. The distance between the Rome and Covey isobases is 142 miles. North of Malone there was very little uplifting, which cuts off about 17 miles. This leaves a breadth transverse to the earth wave of 125 miles. The Canadian data are at present supplied by only a relatively small area in the district of Trent River, which seems to represent the north slope of the earth wave, and thus correlating with the Malone-Covey district.

Parallel with the ice border the wave might have indefinite extent, and no facts are at hand relating to that.

The height of the earth billow at Watertown—that is to say, the uplift in excess of any synchronous rise of the Iroquois water level—is not over 70 feet. With a horizontal amplitude of 100 to 125 miles, this vertical movement may be regarded as a very moderate undulation of the earth's zone of rigidity, and as far within the possible theoretic limits.

It seems probable that the earth wave, of the sort here discussed, was only the beginning of the uplift movement, merely the first effect of the local relief of pressure, and that it was promptly succeeded by or resolved into a general lifting movement that involved the whole depressed area



ISOBASES OF PLEISTOCENE UPLIFT

The isobases over New York State (plate 10) have here been extended suggestively. For discussion see pages 253-254

as soon as the weight of the ice-cap was effectively diminished at the center of snow accumulation.

Comparison of Maps

The reader interested in this study should compare the published maps of Pleistocene deformation of the Great Lakes area. The earliest was by De Geer, in number 67 of the bibliographic list, and reproduced by Salisbury in his Glacial Geology of New Jersey (97, page 201). Coleman did not give a map of isobases. Goldthwait has published several maps, in number 108, pages 465-469; 109, plate 5, facing page 233. In this study the papers by Coleman and Goldthwait should be specially considered.

If De Geer's zero and 200-feet isobases had been drawn parallel with his 400-feet line, they would all represent fairly the deformation west of the 75th meridian. The lines curve too sharply at this meridian to represent facts as now interpreted.

Goldthwait's map (108, page 465) places the hinge line of the early glacial lakes across the Lake Erie basin precisely as in our map; and his latest map (109, plate 5) is in general accordance for the Ontario basin and Canada, when it is understood that his isobases represent only the deformation of the later beaches, taking a line through Hamilton, Ontario, as the hinge line. The accompanying table shows that Hamilton was lifted 98 feet before the beaches were tilted at all; so that 100 feet is to be added to his isobases to make them accord with the present map.

In our small map, plate 12, the isobases of the large New York map have been extended, with the same curvature, across New England on the east and across the Michigan-Huron area on the west. In broken lines are inserted, for comparison, three of Goldthwait's isobases, from his figure 1, in title 108. "A" is his hinge line for lakes Chicago, Maumee, and Whittlesey, which joins our zero line. "B" is his hinge line for the deformed Algonquin beach, which cuts obliquely our 100-feet isobase. "C" is his isobase of 835-feet altitude of the Algonquin plane, or 239 feet of tilting, which lies over our 400-feet isobase. The Algonquin hinge line admittedly had previously received some uplift. If that was as much as 100 feet, it would practically harmonize the maps.

Somewhere, both east and west, the isobases will curve decidedly, to surround the northern center of uplift. Over New England the present lines indicate the maximum of uplift, as any northward bending will reduce the amount of deformation. If the northward convex curvature of Goldthwait's lines is correct, then our New York isobases can not bend much to the north and still connect with his. The northward con-

vexity of the isobases shown in the maps by Goldthwait implies a flat syncline, pitching south. This suggests two centers of uplift, the westward of which might be related to the Keewatin ice-body, and somewhat earlier in time than the eastward movement in response to the waning Labradorian ice-sheet.

There yet remains a question as to the possible uplift of the territory which shows no deformation of the lake shorelines, south of the zero isobases. Either the southern area (1) has not been uplifted at all, or (2) has uplifted equally over a large territory, or (3) some uplifting occurred previous to Lake Maumee. Goldthwait argues for no uplift during the period of time covered by the life of the lakes.

As the isobases of our map certainly represent the total Pleistocene uplift in the Hudson-Champlain Valley, and when extended westward harmonize with the data of the area of the glacial lakes, it seems probable that our zero line is correct for the post-Wisconsin uplift. Bearing on this problem is the fact that only the thin edge of the Labradorian ice-sheet (Wisconsin glacial epoch) extended much beyond the zero isobase in Ohio, Indiana, and Illinois, and not at all beyond it in Pennsylvania and New Jersey. The depression and uplift of the New York-New England area was related to the Labradorian ice-body. The movements of the Mississippi territory may have been somewhat affected by the Keewatin ice-sheet.

Conclusion and Summary

The extension of the isobases of the post-Glacial or marine uplift in the Hudson and Connecticut valleys westward across New Jersey and Pennsylvania and over New York and adjacent parts of Canada is found to correctly indicate the total Pleistocene uplift of all the large area. This is shown in the large map, plate 10.

The marine plane being determined the whole length of the Hudson-Champlain depression, and around the Covey Hill salient to and through the Saint Lawrence Valley, we have a plane of comparison with the plane of Lake Iroquois. The recent fairly accurate measurement of the altitudes of the two planes at the critical point, Covey Channel, the second and final outlet of Iroquois, gives the altitude figures as Iroquois, 1,030, and the marine as 740 feet above ocean.

It is believed and assumed that the time interval between the draining of Iroquois from its Covey outlet and the ingress of the sealevel waters into the Saint Lawrence-Ontario Valley was so short that no considerable land uplift occurred during that episode, and that therefore the vertical distance through which the waters fell, 290 feet, must be approximately

the true vertical interval throughout the whole area reached by the sealevel waters.

Making use of this fixed vertical difference in height of 290 feet in connection with the isobases of total uplift, a table is compiled (plate 11) which for any point where either the Iroquois or the sealevel altitude is known gives us (1) the amount of uplift during glacial time—that is to say, all the time preceding the death of Iroquois; (2) the amount of post-Iroquois (post-Glacial) uplift; (3) the initial altitude of the point before any uplift occurred; and (4) the amount of flooding at any point by the excess uplift of the rising outlet at Rome.

The data of the table also show (1) that the greatest amount of glacial uplift was in the districts that were the earliest relieved from the burden of the ice-sheet; (2) that the most northerly districts reached by Iroquois waters did not rise at all until after Iroquois time—that is, until the sealevel waters were admitted into the Ontario basin; (3) that the splitting of beaches into vertical series of bars is restricted to land north of the Rome isobase, which rose by a wave movement before the extinction of Iroquois and probably after the outlet was shifted to Covey Pass, and the rising of the lake surface ceased; and (4) that the series of multiple bars or split beaches disappear northward, but that all have been uptilted together, as a unit, by the post-Iroquois uplift. The data also imply that no land uplifting took place at any locality while the ice-body lay over it.

The facts prove, what has been assumed by students of the subject, that the uplifting of this part of the continent, following glaciation, was not as a unit or a rigid mass, but by a wave movement as of a slowly bending crust.

Students of the large problem of diastrophism should seek the data for extending the isobasal lines to inclose the area of Pleistocene uplift, and they should not be repelled because the data indicate a greater submergence during glacial time than has been supposed.

Following this trail, the workers in Canada should look for the sealevel beaches and other shoreline phenomena at the elevations given in the table, remembering that the features are likely to be weak in most localities, being formed on a shore that was rapidly lifting; but that a few positive occurrences of shore phenomena outweigh any quantity of negative results.

Bibliography

The titles in the following list are of papers which bear more or less directly on the evidence and work of the Pleistocene waters, glacial and marine, in the Ontario-Saint Lawrence, Champlain-Hudson, and Con-

necticut valleys, and on the land uplift in the area covered by the maps, plates 10 and 12.

For convenient reference in the text the titles are given in numerical order, largely chronologic.

The recent papers which will give a general grasp of the subject are numbers 95, 104, 108, 109, 117, 118, 125, 127.

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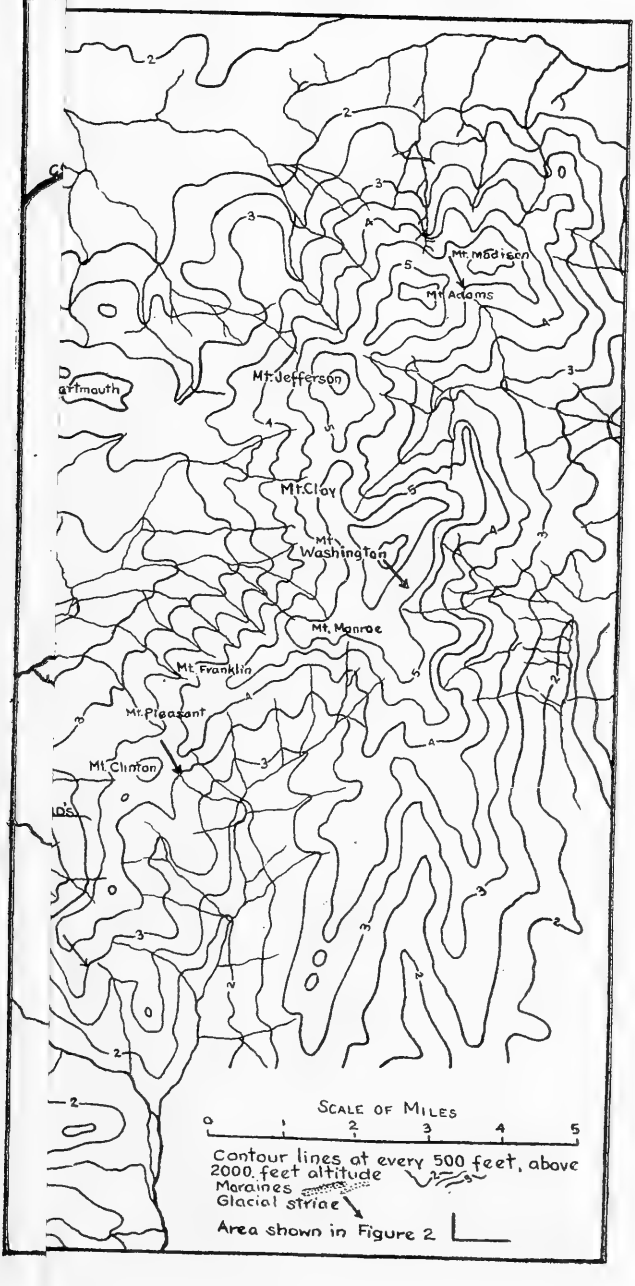
Postscript

Since this article was in paged proof and ready for press the writer has visited the Canadian localities east of Quays in company with Professor Coleman and Mr. H. L. Kerr, of Toronto. Through the generous aid of Mr. Kerr, in furnishing automobile transportation, a large territory was covered during five days of active work, extending from Coburg northeast to Belleville and north to Madoc and Queensboro.

Many new localities were found, of both Iroquois and marine levels, with excellent display of shore features. All the facts confirm the philosophy of this paper. The interval between the latest Iroquois level and the marine plane is 290 feet, the same as in New York. The figures in the tabulation, plate 11, do not require serious change except for West Huntingdon, which station Coleman has always regarded with doubt. We there found a splendid display of Iroquois bars, having a vertical range of 25 feet. The precise altitudes await information concerning the datum points. These Iroquois shore features on the north end of the hill, two miles northeast of West Huntingdon station, prove by their strength and range a long life of the waters at this northern point and indicate that the lake reached far northward from this point before the lake was extinguished. The vertical range of the bars also indicates a greater breadth of the wave of land uplift than was implied by the printed figures and brings the lake history and land uplift in Canada into harmony with the facts in New York.

The figure 25 for splitting of beaches at Madoc should be changed to 30, and the figure 3 under West Huntingdon should be 25. The altitudes of the two stations are subject to corresponding change.

June 2, 1916.


Mt. Madison
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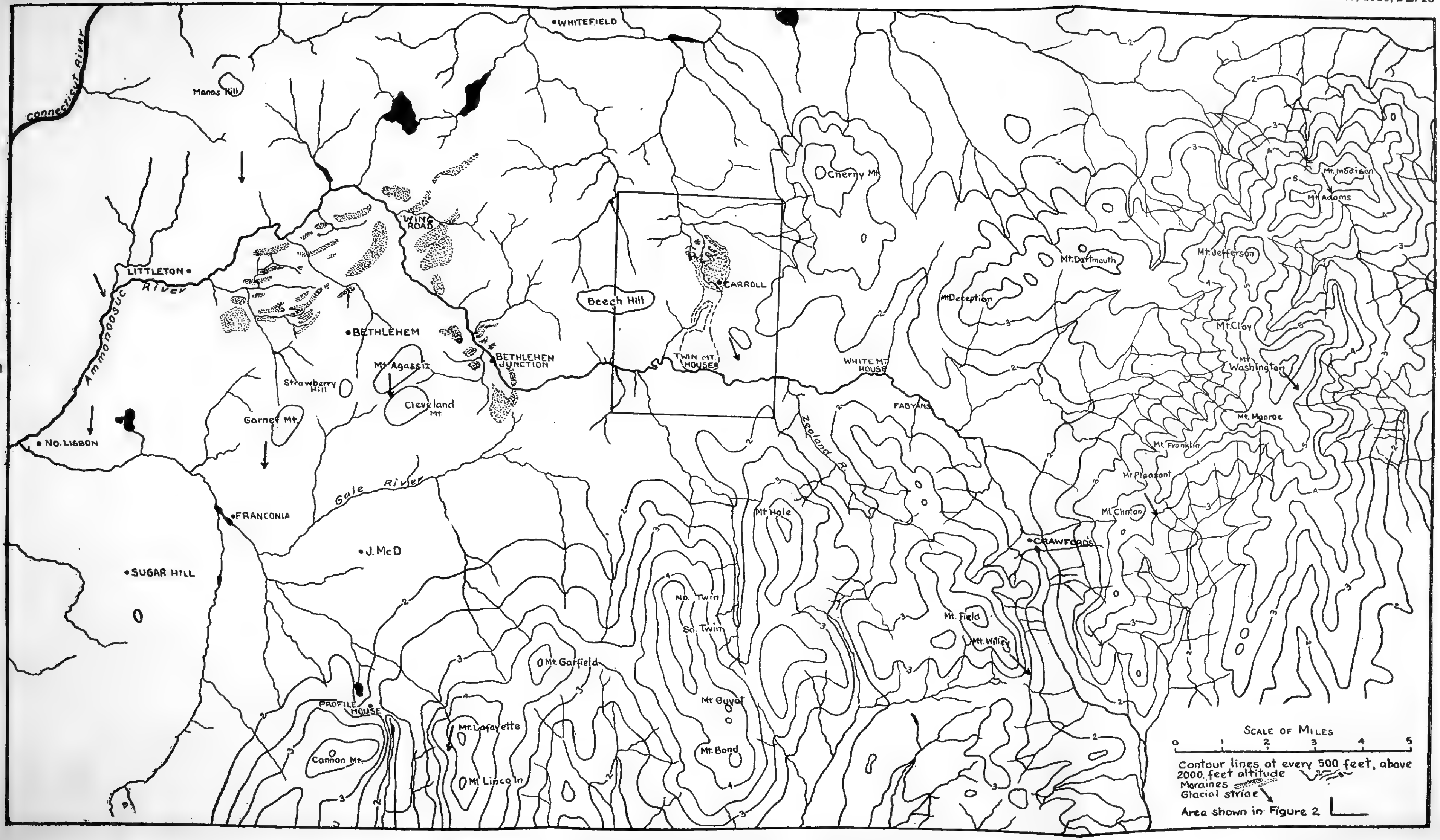
SCALE OF MILES
0 1 2 3 4 5
Contour lines at every 500 feet, above 2000 feet altitude
Moraines
Glacial striae
Area shown in Figure 2



AMMONOOSUC VALLEY AND NEIGHBORING SLOPES OF THE WHITE MOUNTAINS

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GLACIATION IN THE WHITE MOUNTAINS OF NEW HAMPSHIRE [1]

BY JAMES WALTER GOLDTHWAIT

(Presented before the Society December 29, 1915)

CONTENTS

INTRODUCTION

Three years ago I undertook a study of evidences of glaciation, both by ice-sheet and valley glaciers, in the White Mountains of New Hampshire. The observations of that season were directed mainly to cirque development in the "gulfs" or "ravines" around Mount Washington and to the proofs of regional glaciation on the highest peaks. An unexpected result of this study was the discovery that most, if not all, of the local

[1] Manuscript received by the Secretary of the Society March 1, 1916.

glaciation preceded the last regional glaciation—a conclusion in disagreement with those of Louis Agassiz, Prof. C. H. Hitchcock, and Dr. Warren Upham in New Hampshire, and of the late Prof. R. S. Tarr in Maine. Having the opportunity during the past summer to study the problem further, I chose a field more particularly known to the three pioneers in New Hampshire glacial geology. With a small party, organized in coöperation with the Dartmouth Outing Club, I spent four weeks in the Ammonoosuc Valley, Franconia Mountains, and Mount Moosilauke, examining in detail the evidence hitherto published and gathering new pieces of evidence where opportunity offered. During most of the time the party camped in tents, but while working in the district around North Woodstock and Mount Moosilauke we occupied a newly completed cabin of the Outing Club at Agassiz Basin. For generous support of the project, I am indebted to Rev. J. E. Johnson of the class of 1866 of Dartmouth College, the Honorary President of the Dartmouth Outing Club. While it is realized that we have collected by no means all the interesting evidence of glaciation which could be gathered in this field, it is thought that the observations presented in this paper will at least show that the evidence of glaciation of the White Mountains by local alpine glaciers, or by a local ice-cap, *at the close of the last Glacial epoch* are fictitious, although, as suggested by the studies of three years ago, it is clear that there was a limited development of alpine glaciers on the highest mountains at some stage or epoch *prior to* the passage of the last ice-sheet over them.

Glaciation related to the Bethlehem Moraine

QUESTIONS RAISED BY REPORTS OF EARLIER OBSERVERS

The country between Bethlehem and the Ammonoosuc River is classic ground for glacial studies. In it Louis Agassiz, fresh from his investigations of Swiss glaciers, in 1847, saw what he confidently described as "unmistakable evidences of the former existence of local glaciers." These evidences he reported in considerable detail after a second visit to the district, in 1870, in the only paper he ever published on glacial geology in New England.[2] A series of sixteen terminal or recessional moraines, composed of material believed to be derived in part from the south, were attributed by Agassiz to a local glacier which had moved northward from Mount Lafayette across the valley of Gale River and the ridge near Mount Agassiz, over the site of Bethlehem village to the Ammonoosuc River (see

[2] Louis Agassiz: On the former existence of local glaciers in the White Mountains. Proc. Amer. Assoc. Adv. Sci., vol. 19, 1870, pp. 161-167.

plate 13). During the existence of the Geological Survey of New Hampshire, Professor Hitchcock, the State Geologist, examined the field, in company with Agassiz, and concurred fully with him in this interpretation of the evidence, although dissenting from Agassiz regarding some "other speculations concerning the existence of glaciers in the neighborhood" which were never published.[3] Hitchcock carried the idea of local glaciation further, describing in his report a number of alpine glacier systems, of which the most important was the Ammonoosuc glacier. This, according to his view, moved northwestward and westward down the Ammonoosuc Valley, after the Canadian ice-sheet had receded from the mountains, and redistributed the drift, building lateral and terminal moraines in the neighborhood of Littleton, Bethlehem, and Twin Mountain House. Cases of transportation of rocks from parent ledges northwestward—or opposite to the regional movement—were cited. Thirty years later Dr. Warren Upham, revisiting the district in which, as a young man, he had worked as Hitchcock's assistant on the State Survey, discovered that the morainic features were more satisfactorily referred to a local White Mountain ice-cap than to a valley glacier.[4] Typical morainic drift with knob and kettle topography was reported by Upham to extend in a nearly continuous belt from near the Twin Mountain House westward past Bethlehem to Littleton—a distance of 12 miles. No new evidence was offered in support of the view that the ice had moved from the mountains northward to the moraines, but the previous observations of Hitchcock were accepted, and the view was adopted that near the close of the last Glacial epoch, when the continental ice-sheet had withdrawn from the district, local snowfall on the White Mountains was sufficiently great to maintain an ice-cap, around the periphery of which a distinct moraine was built.

A careful reading of the evidence presented by these three observers does not convince one of the validity of the conclusions which they drew regarding the source of the ice and the direction of its movement. For example, Agassiz compared the moraines north of Bethlehem to the recessional moraines of the Rhone glacier; yet the topography of the Bethlehem district bears no resemblance to the Alpine valley. The supposed source of the glacier—in the White Cross Ravine, on the northwest side of Mount Lafayette—was apparently not regarded by Agassiz as sufficiently important to be investigated and described, although at the time when he wrote, as now, it was recognized that local glaciers carve out peculiar bowl-shaped ravines or cirques at their heads. According to

[3] C. H. Hitchcock: Geology of New Hampshire, vol. 3, 1878, pp. 233-234.

[4] Warren Upham: Moraines and eskers of the last glaciation in the White Mountains. Amer. Geologist, vol. 33, 1904, pp. 7-14.

Agassiz, this glacier, after descending the side of Lafayette, crossed the Franconia Valley and was thick enough to overtop the ridge between Mount Agassiz and Strawberry Hill (see plate 13); so that it flowed northward over Bethlehem, descending a mile or two farther before it halted at the lines of moraine. In other words, this glacier would have followed the ravine of Lafayette Brook in a northwestward direction nearly to the foot of the mountain, then would have turned abruptly out of its valley, pursuing a northeasterly course across the undulating Gale River lowland; would have pushed over the Mount Agassiz ridge through a col at least 800 feet above the Gale River country, and thence would have reached down over Bethlehem in a path transverse to the Ammonoosuc Valley, stopping near the river. Such a course would have been entirely disobedient to topography. A glacier or a group of glaciers, heading on Mount Lafayette and Mount Garfield, would naturally continue the downhill course past Franconia village instead of leaving it to pursue an uphill path across country to Bethlehem. Before it could pass over the Mount Agassiz ridge the glacier would have had to fill the Gale River basin to a height of more than 800 feet above its floor, east of Franconia, forming an extensive sheet or lakelike expanse of ice, whose main outlet would be northwestward past Franconia to North Lisbon. Agassiz says, indeed, that

"Those familiar with the topography of the Franconia Range, and its relation to Picket Hill and the slope of Bethlehem, will at once perceive that the glacier which deposited the front moraine to the north of Bethlehem village must have filled the valley of Franconia to and above the level of the saddle of Picket Hill, making it at least 1,500 feet thick, if not more; thicker, in short, than any of the present glaciers of Switzerland." [5]

Between such a glacier and the well contained, methodical valley glaciers of the Alps the resemblance is slight indeed. Here, as in subsequent literature on local glaciers of the White Mountains, one sees a tendency to overlook the differences between valley glaciers and ice-sheets. From Agassiz's comparison of the moraines of Bethlehem with those of the Rhone, one would expect to find narrow, steep-sided ridges, arranged in concentric curves on lines of recession of an ice-tongue; but he does not definitely describe their form and trend and does not map them. He offers no evidence of striation by the local ice movement, and, although he reports that the southward movement of rock material by the regional glaciation is everywhere plain and unmistakable, he offers no definite proof that any drift boulders have been moved northward by the local glaciation. He says that "a careful examination of these [erratic boul-

[5] Op. cit., p. 165.

ders] shows beyond a doubt that they came from the White Mountains and not from the northern regions, *since they overlie the typical drift which they have only here and there removed or modified*."[6] In one instance, perhaps, Agassiz did consider the composition of erratics in relation to that of the bedrock, for he says regarding certain "longitudinal moraines" east of Mount Agassiz that they "are particularly interesting as connecting the erratic boulders on the north side of the Franconia Range with that mountain mass, and showing that they are not northern boulders transported southward, but boulders from a southern range transported northward."[7] But nothing is said regarding the type of rock concerned, and the context leaves one in doubt whether lithological resemblance was considered. Thus in undertaking to fit an alpine glacier into a low undulating country along a path transverse to the slopes, in its complete lack of evidence of grooving by the local movement, and in its failure to furnish specific evidence of a northward dispersion of rock debris from known sources, Agassiz's paper raises questions which could only be answered by more critical field-work.

Hitchcock's treatment of the problem places it more definitely before the reader, since it furnishes a larger number and variety of observations and states more clearly the need for discriminating between the regional glaciation and the local movement; yet misgivings as to the conclusiveness of the evidence are aroused by passages like those quoted in the following sentences, with the addition of italics for the emphasis of significant phrases:

> "He [Agassiz] found evidence of a movement opposite to that of the general drift. Hence this must have been different from the common drift, and, taken in connection with the other features described, it was found to have been local, and existed in the decline of the ice period after the continental sheet had mostly disappeared. *The action was rarely sufficiently energetic to score the ledges.* Agassiz does not rely upon that class of evidence in maintaining his position. The ice of this Franconia-Bethlehem movement has passed over the ledges *but has not smoothed or striated them.* The boulders which went southerly in obedience to the southeast movement were simply pushed back *towards* their source; *and we find very few cases of their protrusion beyond their starting point.*"[8]

Turning to the White Cross Ravine ("the prominent valley back of Eagle Cliff"), which was regarded by Agassiz as the source of that glacier, Hitchcock devotes a page to a quotation from his father, Edward Hitchcock, who described moraine-like deposits made by new rock slides at the

[6] Op. cit., p. 164. The italics have been added.
[7] Loc. cit.
[8] Op. cit., p. 239.

head of the ravine. How this supports the view that the ravine was once occupied by a glacier is not clear, since it plainly implies that ridges which might be mistaken for moraines are in reality modern landslide deposits, and not moraines at all. Again, he reports that "boulders of Franconia breccia, like the ledge composing Eagle Cliff" [near the Profile House], occur near J. McDonald's in Franconia, 2 miles from the ravine, and in line with the Mount Agassiz col (see plate 13, on which the location of McDonald's is marked "J. McD."). "The distance of their transportation is about 2 miles, and no locality of this rock is known to exist nearer McDonald's than Eagle Cliff. Many of these blocks are 4 feet in length."[9] At first sight this appears to be sound evidence of a northward movement, but it raises the question whether, after all, in a country so generally covered with drift it is safe to assume that the localities where certain types of rock are known to exist are the only sources of the drift. Hitchcock's interpretation is not strengthened by his admission that "the ledge near [McDonald's] does not show any ice marks from the local glacier, *but there are appearances upon it of the usual southwest movement of the neighborhood.* "North of McDonald's the surface of the drift is smooth and nearly flat. This is to be explained by the passage of the ice over it, as in Bethlehem."[10] If smoothness and flatness is to be used as an evidence of the passage of the ice over a surface for a second time, then local glaciation is suggested by similar smooth tracts of limited extent all over New England. There is nothing peculiar about the country referred to by Hitchcock. A moraine-like ridge which trends northwest-southeast is mentioned as possibly connected with the Bethlehem glaciation "as a medial moraine or lateral moraine,"[11] but no reasons are offered for attributing it to a local movement rather than to the ice-sheet, which, according to Hitchcock, moved southwestward. "Between Bethlehem Street and Littleton is a Baptist church, near which I observed boulders 15 feet long, 10 wide, and 10 high, whose source is estimated to be from 300 to 500 feet to the south uphill. Their transportation down this slope I ascribe to the same local glacier."[12] No evidence is offered for the belief that these came from the ledges which lie just south of them rather than from sources just north of them. The uncertainty of the value of the observation is increased by the statement, a few lines beyond, that "the eastern slope of the hill between Bethlehem Street and station is strewn with large boulders *of material similar to the nearest ledges.*" One is led to suspect that this is the

[9] Op. cit., pp. 240-241.
[10] Loc. cit.
[11] Loc. cit.
[12] Loc. cit.

prevailing condition. If that is so, the presumption is that the boulders have been carried to their places by the ice-sheet.

In Doctor Upham's paper of 1904 a wholly new conception of the Bethlehem moraines was presented. Upham concurs in Agassiz's view

"that the morainic drift . . . was brought from the south, being amassed along the northern edge of ice fields that sloped down from the northern edge of the Franconia and Twin Mountain ranges; but I could not trace the many and mainly parallel morainic ridges or series of knolls and hillocks which his description led me to expect. Instead of separate and well defined small frontal moraines, like those which I have seen in the glens and valleys around Ben Nevis and Scrawfell, marking intervals of halting in the retreat of the latest local glaciers, the ridged and knolly drift deposits north of Bethlehem appear to me to be an indivisible and promiscuous morainic belt, running there from east to west, with a width of one to one and a half miles, quite like the typical moraines of the continental ice-sheet in their course through Minnesota and adjoining States. . . . The morainic belt close north of Bethlehem, which I then first examined, was found . . . to have a considerable extent from east to west in the Ammonoosuc Valley. Beyond that portion, traced from the vicinity of the Twin Mountain House westward to the south part of the village of Littleton, a distance of twelve miles, this moraine doubtless turns to the southwest and south, and sweeps circuitously around the highest ranges of the White Mountains, to connect again, from the east and north, with the east end of the part so traced. Its small hills and short ridges usually rise 15 to 30 or 40 feet above the intervening and adjoining hollows, but sometimes to heights of 50 to 100 feet; and in many places, as at Littleton, its accumulations are more massive than at Bethlehem.

"The material of this belt is chiefly till, with some modified drift, as kames, or knolls of gravel and sand. The contour is very irregular, in multitudes of hillocks and little ridges, grouped without order or much parallelism of their trends. Everywhere in and upon these deposits boulders abound, of all sizes to rarely 5 or even 10 feet, or more, in diameter, being far more plentiful than in and on the adjoining smoother tracts of till throughout this region." [13]

This interpretation of the topography and structure of the moraine by one experienced in tracing morainic belts avoids the difficulties raised by Agassiz's theory of a valley glacier; but it introduces a new problem of scarcely less interest. If the Bethlehem moraine marks the border of an ice-sheet, was it built at the southern edge of ice which still covered eastern Canada and northern New England, having withdrawn from the White Mountains, or was it built at the northern edge of a smaller, more local ice-cap which covered the White Mountains, being supported by local snowfall after the Canadian ice had withdrawn? As shown in the quotation just cited, Upham adopted the latter view, influenced, it may have been, by the idea that the superiority of altitude of these highest mountains of New England would require a continuance of glacial climate

[13] Op. cit., pp. 10-12.

locally after the conditions on the surrounding lowlands had become nearly normal. In his paper he alludes to Agassiz's belief that the erratics on the moraine came from the south, and quotes Hitchcock on the transportation of large boulders of coarse gray granite 4 miles down the Ammonoosuc Valley, in a westward course, to the Twin Mountain House—an observation which will presently be discussed. He adds nothing new, however, in the form of lithological evidence, to show that there was a northward dispersion of drift toward the Bethlehem moraine. After reporting that the moraine runs continuously from near the Twin Mountain House past Bethlehem to Littleton—not less than 12 miles—Upham proposes to correlate this Bethlehem moraine with patches of similar topography and structure described by Agassiz near Center Harbor (south of the White Mountains) and by Stone in the Androscoggin Valley (east of them), all lying, according to his hypothesis, on a moraine which completely encircles the White Mountains. In view of the fact that such a moraine would have a length of 100 to 150 miles, and that of this a mere scrap, 12 miles long, has been seen to possess continuity, and two other smaller scraps are reported, in a region where kames, eskers, and boulder-strewn drift deposits are familiar features, the correlation can not be recognized as other than a working hypothesis, to prove which it would be necessary to carry on field studies around the greater part of the circle. Without more definite proof of a transportation of erratics radially outward and downward from the White Mountains, one is justified in assigning at least equal value to the hypothesis that the Bethlehem moraine, as well as those east and south of the White Mountains, was built at the southern border of the Canadian ice-sheet while it retired from the district, leaving the White Mountains comparatively free from ice.

The field-work around Mount Washington in 1912 had led me to look with disfavor on Doctor Upham's hypothesis. Had a local ice-cap been left on the White Mountains, as he supposed, it would in time have given place to radiating valley glaciers, and the records of these glaciers ought to be discoverable in the form of moraines in the valleys draining the central range. The lack of morainic deposits at the lower ends of the White Mountain ravines seemed to indicate that the cirque-cutting glaciers operated before the last regional glaciation, and were not re-established by local snowfall in the closing stage of the glacial period. I was therefore not surprised to find evidence which seems to indicate that the Bethlehem moraine was built at the southern margin of the Canadian ice-sheet rather than at the northern margin of a White Mountain ice-cap.

Our study of the Bethlehem district included an examination of its

topography, especially the ravines on Mount Lafayette, observation and mapping of the moraines in question, and an investigation of the direction of dispersion of boulders in the drift.

TOPOGRAPHY OF THE MORAINE

The Bethlehem moraine field is neither a series of distinct and separate recessional moraines, like those of the Rhone, nor an "indivisible and promiscuous morainic belt," although as a general statement the latter description comes nearer the truth. The fact is, the Ammonoosuc Valley north of Bethlehem and Maplewood and westward from Bethlehem Junction as far as Littleton is occupied by a group or chain of recessional moraines whose thickness in places probably exceeds 300 feet. This is shown on the map, plate 13. The belt can be resolved into its component parts only by making a thorough traverse of the district on foot and giving full attention to topographic detail, such as linear mounds and boulder belts, the alignment of sags and swells, and of knobs and kettles and of intervening belts of smoother surface. In a few places the irregularity of surface is strong enough to gain recognition in the 20-foot contours of the Whitefield quadrangle of the United States Geological Survey, in spite of overgeneralization and failure to portray index forms to the degree now observed by the topographers of the Survey. Thus about a mile southwest of Wing Road, where the road to Bethlehem reaches the top of the hill, depression contours show two undrained hollows whose depth considerably exceeds 20 feet. They are in fact very conspicuous steep-sided kettle-holes, surrounded by high knobs of one of the most pronounced and continuous morainic lines in the district. Linear development of morainic ridges is also suggested where contours between 1,200 and 1,300 feet across the north-south road, a mile and a half west of Bethlehem. Although the kamelike mounds and gentler swells are in many places subcircular, or, when linear, are oriented without order, there is a prevalent east-west trend, or, more accurately, a trend of north 65° east-south 65° west, which is apparent at once to one who traverses the field on foot, and is shown on the map, plate 13. In the district between the Bethlehem-Littleton State road and the Ammonoosuc River only one exposure of bedrock was discovered during a week of search. This is a few rods southwest of a little ice pond a mile north of Bethlehem village. Rock exposures occur in the Ammonoosuc River at Apthorp (near Littleton) and above the mouth of Alder Brook; but the hills south of it, which rise from 200 to 400 feet higher, seem to be completely covered by, and largely composed of, glacial drift. In a large degree, therefore, the course of the Ammonoosuc between Wing Road and Littleton

appears to have been determined by the east-west trend of the ice-front at the time it built the northernmost line of moraine.

Agassiz reported that

"the moraines show unmistakably by their forms that they were produced by the pressure of a glacier moving from the south northward. This is indicated by their abrupt southward slope facing, that is, toward the Franconia Range, while their northern face has a much gentler descent. The steeper slope of a moraine is always resting against the glacier, while the outer side is comparatively little inclined. The form of these moraines, therefore, as well as their position, shows that they have come down the Franconia Mountains." [14]

Regarding this, I can only say that when the whole territory in question is examined one finds steep slopes as often on the northern sides of the morainic ridges as on the southern sides; in fact, were I compelled to express an opinion as to the prevalence of steep slopes on one of the two sides, I would say that they were to be found more often on the north.

STRUCTURE OF THE MORAINE

The most striking feature of the Bethlehem morainic belt is the abundance and great size of the blocks which lie on its surface. At first sight one suspects that there are ledges close beneath, which have furnished the ground moraine with an overabundant supply of newly quarried rock. The aspect resembles that of granite ridges, where ice-borne blocks and glaciated outcrops share a large part of the surface. The utter absence of ledges, however, is soon realized, and at the same time one finds to his surprise that beneath the block-strewn surface there is not ground moraine, but stratified drift. Excavations by the roadside in many places—most of them shallow, but a good many of them 10 or 15 feet deep—prove beyond a doubt that the morainic ground is chiefly composed of sands, gravels, and cobbly boulder beds, with the finer sediment predominating. Locally, till containing ice-worn stones composes the knobs and swells; but this is exceptional. Although Upham reported that the deposits were composed of till, extensive road construction of the last five or ten years has stripped the moraine of its disguise and revealed it as essentially a kame moraine belt. This, to my mind, is significant; for such a condition would be more easily accounted for by the retirement of the front of the Canadian ice-sheet northward and westward from the Ammonoosuc Valley—which drains in that direction—than by the retirement of the front of a local White Mountain ice-cap southward to the foot of the mountains. The Canadian ice-sheet, with its front covering the northward bend of the Ammonoosuc between Bethlehem Junction and Little-

[14] Op. cit., p. 164.

ton (as shown in plate 13), would dam the Ammonoosuc River, holding it up to a level approximately the altitude of the moraine summits; for there is no outlet above Wing Road lower than the 1,320-foot pass just south of Bethlehem Junction; and even this would hardly appear to have served, inasmuch as the ice at the time it lay against the Bethlehem moraine would probably have dammed up the lower part of the Gale River-South Branch system below Franconia. Indeed, as the map shows, morainic belts similar to those seen by Agassiz and in fairly definite alignment with them extend from the eastern side of the Ammonoosuc above Wing Road in an easterly or northeasterly direction, indicating that during this stage the river was blocked. Among these moraines are three sharply defined hillside ridges, which run obliquely up the slope of the 1,612-foot hill east of Wing Road, resembling the moraines described by Taylor in the Berkshire Hills.[15] There are also broader belts of sag and swell topography. Blocks abound on most of these, save where they have been removed in cultivating the fields and built into stone walls; and stratified drift, while not unmixed with till, is the dominant type of deposit.

TREND OF THE MORAINE

The map, although not as complete as it may be made by further field work, shows the location and trend of the more definite lines of moraine. The full width of the belt, it will be seen, is 2 miles. It obviously bears no relation to the Mount Agassiz saddle or to any local glacier from the south. Such glaciers would be comparatively narrow, and would deposit moraines whose curvature was convex northward, where they terminated, fanlike, on the lowland. The local curvatures of the Bethlehem moraine, which are slight in every case, are definitely convex southward. The moraine therefore cannot be assigned to local glaciers moving northward. As Upham discovered, it marks the border of an ice-sheet. His statement, however, that this moraine runs continuously eastward up Ammonoosuc Valley to Twin Mountain House is inaccurate. While there are morainic deposits east of Maplewood, south of Bethlehem Junction, and around the Twin Mountain House and at Carroll, these are so far out of line with the moraines east of Wing Road that they pretty surely mark different stages of retreat.

The trend of the morainic lines, it will be seen, is perpendicular to the course of the striæ, as shown by arrows on the map, which are based on observations of Hitchcock, with some additions. While the striæ themselves do not indicate whether the movement was northward or south-

[15] F. B. Taylor: The correlation and reconstruction of recessional ice borders in Berkshire County, Massachusetts. Journ. Geol., vol. 11, 1903, pp. 323-364.

ward, the dispersion of drift from northerly sources to southerly resting places leaves little doubt concerning it. In fact, both Agassiz and Hitchcock, although firm advocates of the theory of local White Mountain glaciers, accepted all the striæ as records of the general southward movement of the continental ice-sheet. It is of course true that a local ice-cap on the White Mountains would be likely to have a border here, trending northeast-southwest, since this is on the northwest side of the mountains. The question whether the moraine marks a local ice-border or a part of the Canadian ice-border, therefore, must be settled primarily by the direction in which erratic stones have traveled in the construction of it.

SOURCES OF THE DRIFT IN THE MORAINE

The difficulty of stating definitely the paths traveled by erratics is even greater than Agassiz pointed out. In addition to the chance for confusing an earlier, southeastward movement with a later, northward or northwestward one—which might account for finding "very few cases of their protrusion beyond their starting point"—there is the highly important circumstance that a drift blanket covers a very large per cent of the surface, effectively concealing the rock structure; and there is also the fact that this structure consists of gneisses and other granitoid rocks which bear resemblances to one another, while varying within themselves in texture, structure, and composition. Within the district just described Hitchcock recognized "Bethlehem gneiss," "Lake Winnepesaukee gneiss," and "porphyritic granite," with small areas of "Coös mica schists" not liable to be confused with the gneissic rocks. So far as the "Lake Winnepesaukee gneiss" is concerned, it seems to me that in this district it is merely a border-zone facies of the "Bethlehem gneiss." It is a well foliated biotite gneiss, similar in all respects to the border zone of the "Lebanon granite" of Hanover, New Hampshire, which Hitchcock himself recognized as the counterpart of the "Bethlehem gneiss." The porphyritic gneiss is more distinct, carrying phenocrysts 1½ to 2 inches in diameter; yet there is opportunity to confuse it with the more porphyritic facies of the "Bethlehem gneiss." There appears to be ample opportunity for disagreement in the discrimination between these structures according to lithological composition. There is much greater cause for disagreement regarding the extent of surface which each type of rock occupies, since, as already stated, most of the area is covered with drift. The outlines of the several areas here, as elsewhere, on the geological map of New Hampshire in Hitchcock's atlas of the State, are manifestly arbitrary and unnatural. Boundaries are drawn in arcs of circles or in straight lines for distances of from 2 to 10 miles; plutonic masses are

matched in a strange and unaccountable mosaic, rarely obedient to the laws of underground structure on the one hand or those of topography on the other. It is a question whether an attempt to build up a complete bedrock map in solid colors is justified in a region so generally concealed by glacial deposits. Only an outcrop map with a background of glacial drift could be trusted.

Now, the fact is that it is the testimony of all workers in this field that the drift is composed almost wholly, if not wholly, of debris of native rock and of rock from areas in the northwest. Agassiz offered no definite lithological evidence of boulders transported northward; Hitchcock candidly affirmed that the boulders which went southward in obedience to the southeastward movement of the ice-sheet were simply pushed back *part way* to their sources by the subsequent reverse movement. So far as the Bethlehem moraine is concerned, the only specific piece of evidence of a northward movement is Hitchcock's statement of the occurrence of boulders of Franconia breccia near McDonald's, 2 miles north of Eagle Cliff, referred to on an earlier page, as being on the cross-country course of Agassiz's glacier. I visited this locality in 1915, but was unable to find blocks of Franconia breccia there. The McDonald house was long ago abandoned and the farm has become overgrown with woods. Blocks and boulders are conspicuous in a pasture an eighth of a mile west of the site of the McDonald house, but they are of granite gneiss, like the ledges of Garnet Mountain and Mount Agassiz, just north of them. Between McDonald's and the foot of Mount Lafayette, at Eagle Cliff, the country is thoroughly drift-covered and I found no outcrops. Whatever there may be in the drift at McDonald's, it certainly is not safe to assign it to sources in the Franconia Mountains when so much of the region is concealed.

So far as my own observations extend, the boulders on the Bethlehem moraines are either of the native rock—as mapped by Hitchcock—or of rocks which were known by him to occur a short distance northwest of the point of observation. On the northernmost line of moraine, between Apthorp station and the mouth of Barrett Brook (which flows northwest from Bethlehem), angular blocks of foliated biotite gneiss abound—the "Winnepesaukee gneiss" of Hitchcock or a border-zone facies of the "Bethlehem gneiss," as already explained. East of Barretts Brook and as far as Wing Road rounded boulders of coarse porphyritic gneiss predominate, coming apparently from a area mappel by Hitchcock between Manns Hill and Wing Road, immediately north of here, where there are some outcrops. The smaller stones in the drift include many of these types, together with iron-rusted "Coös schists" and quartzites and green-

ish schists and intrusives of the "Huronian" belt—a group of rocks which are almost certainly absent from the district south and east of Bethlehem, but are widely exposed to the north and west in the Dalton Range and Manns Hill. On the morainic country which forms the present drainage divide south of Bethlehem Junction, near the Gale River Forest Ranger Station—considered by Agassiz and Hitchcock to mark the confluence of glaciers which moved northward from the Franconia Mountains—boulders of porphyritic granite and granite gneiss are common. The presence of both types of rock, in place, within the next few miles northwestward makes it unnecessary to suppose that they came from the mountains on the south. On the other hand, a quartz porphyry which is widely exposed on the main north peaks of Mount Lafayette, at the head of the White Cross Ravine, from which Agassiz's glacier was supposed to have come, seems to be wholly absent from the drift at the north base of the mountain, occurring only sparingly in small torrent-carried stones in the bed of Lafayette Brook. There seems to be no logical ground for assigning a northward movement of ice to this district, but ample reason to believe that the movement was southward.

ABSENCE OF CIRQUES AT THE SOURCE

Finally, there remains the question whether evidence of a local glacier occurs at the heads of the ravines on the northern slope of Mounts Lafayette and Garfield. These mountains rise to altitudes of 5,269 and 4,519 feet respectively. To the south of Lafayette a long, rather straight ridge is capped by the summits of Lincoln, Liberty, and Flume Mountains. To the east of Garfield, the North and South Twin, Bond, and Guyot offer additional areas for local snowfall (see plate 13). No detailed contour map has ever been made of this portion of the mountains and no reports of bowl-shaped ravines have appeared. I was prepared, however, to find signs of glacial sculpture on the Franconia Mountains like the cirques on the Mount Washington Range. This expectation was not fulfilled. The White Cross Ravine, at the head of Lafayette Brook, identified by Hitchcock as the starting place of Agassiz's glacier, is a characteristic torrent-carved valley of Preglacial date, V-shaped in section, rather straight in trend, but with alternating spurs which a valley glacier would have removed. Its middle course is narrow and steep-sided and not at all troughlike; its head, while somewhat flaring, like a funnel, is not bowl-shaped; although partly cliffed, it does not rise in a semicircular headwall, and there is no hollowing out of the floor there, as in Kings, Tuckermans, and other ravines on the Mount Washington Range. If a local glacier ever formed in the White Cross Ravine, it was

too feeble and short lived to make a true cirque out of it. Along the sides of the brook, from the base of the ravine head for about a mile down valley, blocks and smaller fragments of rock are massed in curious linear ridges or mounds, which run longitudinally—never transversely—to the ravine. Doubtless they are landslide deposits like the one which Edward Hitchcock observed and described in 1850, the year after it fell.[16] The steep sides of the ravine within a mile of its head are covered with loosely packed blocks, which, half buried in moss and clothed with a struggling spruce and hardwood forest, offer footing which is precarious, even dangerous, to pass over. With the possible exception of a slight sapping and steepening where the valley heads against the peaks of Lafayette—work which might be accomplished by nivation—I can not see that local glaciation has been recorded here. The oversteepened condition of slopes which gave rise to the landslides is adequately accounted for by regional glaciation. It is a condition not confined to the valleys, but met with also on mountain flanks which overlook broad lowland districts.

CONCLUSIONS FROM EVIDENCE IN THE BETHLEHEM DISTRICT

Agassiz's view that the Bethlehem moraine was deposited by a local glacier, descending northward from the Franconia Mountains, is rejected for the following reasons:

1. The topography between Mount Lafayette and the Bethlehem moraine is inhospitable for a glacier of the alpine type, offering no continuous downhill path, but requiring an open, cross-country course of considerable relief.

2. At the alleged source of the glacier—the White Cross Ravine—as well as in the neighboring ravines, no cirque cutting or trough cutting is evident.

3. The moraines compose a wide belt which trends northeast-southwest for several miles, at least, without relation to the narrow course which Agassiz assigned to the local glacier, and without the northward convexity which his theory would require.

4. There is no trustworthy evidence that drift material has traveled northward to the moraine.

5. All observed striæ and grooves can be referred to the southward movement of the continental ice-sheet, as Agassiz and Hitchcock did refer them.

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[16] E. Hitchcock: Description of a slide on Mount Lafayette, at Franconia, New Hampshire. Amer. Journ. Science, 2d series, vol. 14, 1852, pp. 73-76.

The view of Doctor Upham, that the moraine marks the northern limit of a local White Mountain ice-cap, is also rejected for the following reasons:

1. While there is abundant evidence of a southward movement of drift to the moraine, there is no reliable evidence of a northward movement of it.

2. Striæ run in a north-south or northwest-southeast direction. While they might be interpreted as records of a movement toward the north or northwest, the very definite dispersion of drift in the opposite direction lays the burden of proof on the advocate of a local northward movement. Agassiz and Hitchcock accepted the striæ as records of the southward moving continental ice-sheet.

3. There are no crescentic valley moraines in the ravines such as would be likely to mark halts in the recession of a local valley glacier which survived the local ice-cap.

In place of these two interpretations of the evidence it is held that the moraines were built at the southern edge of the North American ice-sheet when this had retired from the White Mountains, but still covered the adjoining region to the north and blocked the Ammonoosuc Valley, for the following reasons:

1. The trend of the morainic belt for several miles, and as a rule the trend of its component parts, where they are of a linear character, is east-west or northeast-southwest—perpendicular to the course of striæ throughout northern New Hampshire.

2. The great bulk of the drift in the moraine has undeniably traveled southeastward or southward, and, so far as known, all of it has done so.

3. The dominance of stratified drift, which occurs in enormous volumes, overlain by angular blocks from apparently englacial or superglacial sources, suggests obstructed drainage in the Ammonoosuc Valley—a condition easily explained by an ice dam over the lower country on the north and west, but not by an ice-cap which lingered on the highlands after the adjoining valleys had been freed from ice.

Carroll Moraine Field and outwash Plains

GENERAL DESCRIPTION

About 6 miles east of the Bethlehem district, between Beech Hill and Cherry Mountain, is a remarkable group of deposits of stratified drift to which hitherto little attention has been paid. It includes (*a*) a pitted outwash plain just south of the village of Carroll, on the drainage divide between Carroll Stream and the Ammonoosuc; (*b*) a great kame field

north of this plain, a mile long and three-quarters of a mile wide; (*c*) a pair of kame terraces which appear on opposite sides of Alder Brook, south of the Carroll plain, and connect it with (*d*) a more irregular, deeply pitted kame plain just north and west of the Twin Mountain House; (*e*) a prominent esker with associated kames and branch ridges, which runs north and south at the Twin Mountain House, in a course nearly perpendicular to the Ammonoosuc Valley; and (*f*) 2 miles east of here, near the mouth of the Zealand River, another strongly developed esker, which runs east and west beside the Ammonoosuc. It seems not unlikely that this is genetically related to the Twin Mountain esker, although there is no evidence that the two were ever actually continuous. Other esker fragments farther up the Ammonoosuc Valley, near Fabyans, have been known, and, like these, were described in detail by Upham.

TWO OPPOSED VIEWS OF THE ORIGIN OF THE OUTWASH DEPOSITS

In his paper of 1904 Doctor Upham referred to the deposits near the Twin Mountain House as a

"very interesting esker series, partly complex and partly a single conspicuous ridge." . . . "This series of eskers, traced . . . about six miles, near the west base of the Mount Washington Range and north and west of the principal and central area of the White Mountains, was certainly formed by a glacial river, inclosed on each side by walls of the departing ice-sheet, and flowing away from that area, that is, from southeast to northwest and west, in the same direction as the present Ammonoosuc River. It demonstrates, like the Bethlehem moraine, that a remnant of the general ice-sheet was rapidly and continuously melting back from the northwest to southeast, lingering latest on the flanks of the Mount Washington and Mount Willey Ranges." [17]

Upham contributed no evidence to show that this esker was formed by a glacial river flowing westward and northward rather than southeastward and southward, but repeated certain statements of Hitchcock concerning evidences of transportation of erratics down the Ammonoosuc Valley between Fabyans and the Twin Mountain House, the weakness of which will presently be shown.

A study of the deposits around Carroll have led me to take a different view of the conditions under which they originated, namely, that they mark the discharge of glacial drainage *southward* through the Beech Hill-Cherry Mountain pass into the ponded waters of the Ammonoosuc Valley *during the retirement of the Canadian ice-sheet* from these foothills of the White Mountains. The evidence which seems to favor this interpretation rather than that employed by Upham is as follows:

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[17] Op. cit., pp. 12-13.

EVIDENCE OF A SOUTHWARD MOVEMENT OF OUTWASH

The kame and kettle topography of the deposits, although indicating great irregularity in the outline of the ice-border, and requiring the presence of detached masses of stagnant ice in close association with the accumulating gravels and sands, suggests a southward flowing of glacial drainage rather than a northward one. From a steep, high ice-contact slope near the fork of roads at Carroll, the pitted plain which forms the central and most prominent feature of the valley slopes steadily and perceptibly southward, falling in height not less than 20 feet between its north and south borders, from the 1,500-foot contour to the 1,480-foot contour, according to the Whitefield Quadrangle (see figure 1). The surface of the plain, although strongly pitted near its northern edge, becomes smooth over its central part, and at the southern border is interrupted by only a few shallow depressions. There is also a noticeable decrease southward in the number and size of boulders. Near the northern border of the plain they commonly exceed a foot in diameter, but southward they give place to cobblestones and pebbles. From the southeast corner of the plain a nearly level kame terrace reaches southward along the State highway for over half a mile, as shown by the contours of the United States Geological Survey map, connecting at last with the extensive kame plain northwest of Twin Mountain station. A similar terrace occurs on the west side of the pass, as shown in figure 1. In the more southerly kame field, occupied in part by the golf links of the Twin Mountain House and in part by pastures, there is a very noticeable tendency among the hillocks and swells to reach a common level, though there is no such perfect continuity of flat surface here as in the Carroll plain. This accordance of hillocks gives the deposit the appearance of a rude, incomplete delta. Near Twin Mountain House it envelops kames and an esker of earlier date. According to the map, the altitude is about 1,460 feet. A deep cut at the bend of the Maine Central Railway shows that bedrock and block-filled boulder-clay lie but a short distance beneath the surface, and suggests that some of the knolls which interrupt the kame plain are of that character, standing too high to be buried by the outwash. Other sections along the southern border of the plain, however, show large boulders and blocks imbedded in the sands and gravels of the kames. The absence at both the Carroll and Twin Mountain plains of frontal lobes, such as are built by distributary streams on their deltas, may be due to lingering masses of ice at their outer margins. The continuous southward slant of the top of the plains and kame terraces between Carroll and the Ammonoosuc supports the view that the outwash gravels and sands were discharged southward through the pass into the

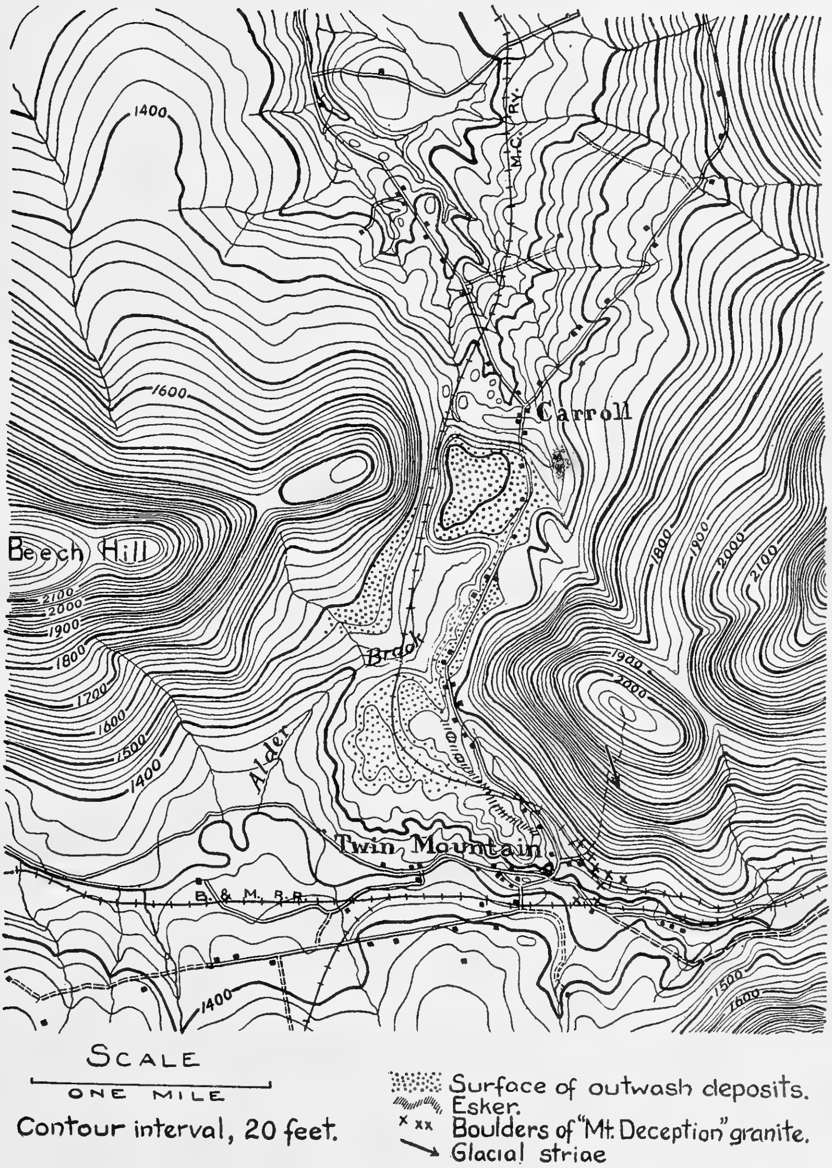

FIGURE 1.—*Carroll District, showing outwash Deposits*

From Whitefield Quadrangle, United States Geological Survey

Ammonoosuc Valley while the ice-masses still lingered there, although the main body of the ice-sheet had retired to the north side of the watershed. On an earlier page it was pointed out that the thick deposits of stratified drift in the kame moraines north of Bethlehem suggest widespread ponding of the Ammonoosuc waters by an ice-sheet which was retiring northward. Similarly the great pitted plain and kame fields of Carroll seem to require an ice-dam so placed as to hold the waters of the Ammonoosuc up to or above the level of the floor of the Beech Hill-Cherry Mountain pass. The Carroll deposits record an earlier, and the Bethlehem moraine a later, stage in the withdrawal of this great ice-dam from the temporary Lake Ammonoosuc. The theory of Doctor Upham, that the Canadian ice had withdrawn from the district north of the mountains and had left a local ice-cap on the highlands, with a reentrant angle near Cherry Mountain, offers no reason for static waters in which delta-like plains might accumulate; for there would be nothing to prevent the free flow of waters northward by Carroll Stream past Whitefield to the Connecticut River near Lancaster (see plate 13). The presence of so much stratified drift, therefore, as well as the southward slope which distinguishes its surface and the southward decrease in the coarseness of material, is reason for supposing that the ice-sheet concerned in its construction was the Canadian sheet on the north and not a local White Mountain ice-cap on the south.

DISPERSION OF BOULDERS NEAR THE TWIN MOUNTAIN HOUSE

It is pertinent now to examine the evidence first reported by Hitchcock and later used by Upham, that boulders near the Twin Mountain House have been transported down Ammonoosuc Valley by ice moving outward from the White Mountains. Hitchcock's statement is as follows:

> "In the fields east of the Twin Mountain House there are hundreds of boulders of Mount Deception granite, often 12 feet in length. The underlying rocks, for the four or five miles distance between the Twin Mountain House and Fabyan's, are of very different material. Hence this is an example of materials transported westerly a distance of four miles. This cannot have been done by water—the blocks are too large. A local glacier sliding over the more ancient drift must have been the agent of transportation. This lateral moraine east of the Twin Mountain House is quite conspicuous, and the most readily accessible of any examples known. It may be seen from the train, a short distance east of the station." [18]

On reading this paragraph, it was obvious that although these blocks might have come westward from Mount Deception, over areas occupied by different types of rock, as Hitchcock supposed, it was at least equally possible that they might be found to have come in a southeastward course

[18] Op. cit., p. 242.

from ledges of the same composition as Mount Deception, unknown to Hitchcock and Upham. Accordingly, when we reached this part of the field, search was made on the wooded slope of the 2,060-foot hill immediately to the north of the blocks in question (see figure 1). A well constructed path which enters the woods at the Maine Central station and runs to Cherry Mountain ascends this slope. For the first 300 or 400 feet of vertical ascent one finds an abundance of boulders of the gray muscovite-biotite granite, of the type known to Hitchcock as the "Mount Deception" granite. Coarse pegmatite veins, carrying much white mica, are prominent in the rock, both here and in the blocks in the open fields east of the Twin Mountain House. The granite varies noticeably in composition, especially as regards the amount of white mica. Near the 1,800-foot contour the trail passes a particularly large angular boulder of it, known as "Beechers Pulpit." Fifty yards farther up the slope and perhaps 75 feet higher there is a ledge. The granite exposed there varies from a gneissoid biotite granite on the one hand to a muscovite-biotite granite on the other, the white mica appearing more conspicuously near the pegmatite veins, possibly as a product of exomorphism. Here is the same rock, in place, as that which composes the blocks reported by Hitchcock from the fields east of the Twin Mountain House, half a mile down the hill. On the ledge a lump of quartz in one of the pegmatite veins bears distinct striæ in two places, which run south 27° east (corrected). The map of glacial features in Hitchcock's atlas of New Hampshire shows an arrow at this same place, as a sign that southeastward striæ were observed there. There is therefore every reason to suppose that the boulders noted by Hitchcock moved southeastward a short distance from ledges on this hillside during the passage of the Canadian ice-sheet, and not westward four miles from Mount Deception on a local Ammonoosuc glacier.

Finally, it may be said that the stratified drift of the Carroll Twin Mountain House district contains, besides the local granites and gneisses, greenstones and chloritic schists from the "Huronian" belt of the Dalton Range, which lies a mile or two northwest of it. So far as the esker near the Twin Mountain House is concerned—a splendid example of its class—its course is almost parallel to the striation and drift dispersion by southeastward-moving ice. All lines of evidence point to the conclusion that it was built by a southward-flowing river rather than one which flowed northward.

CONCLUSIONS DRAWN FROM THE GLACIAL FEATURES OF THE CARROLL DISTRICT

In place of former theories, therefore, the following interpretation of the features around Carroll and the Twin Mountain House is suggested:

(*a*) The southeastward advance of the Canadian ice-sheet over the Carroll district during the late stage of glaciation, registered by southeastward striæ on the hill near the Twin Mountain station, picked up blocks of "Mount Deception" granite from ledges there and carried them to the fields at the foot of the hill, east of the Twin Mountain House. (*b*) As the ice departed from the district, it withdrew first from the flanks of Cherry Mountain and the Twin Mountain Range, still covering the lowlands of the Ammonoosuc and Carroll Stream. Along one of the main lines of glacial drainage, in a canyon or tunnel draining southward from the Beech Hill-Cherry Mountain gap, the high esker at Twin Mountain House and related kames were built. (*c*) As the ice melted out of the pass, and as the Ammonoosuc Valley around Twin Mountain station, still dammed by the ice-sheet between Bethlehem Junction and Wing Road, came to be occupied by a lake, the continued discharge of glaciofluvial torrents southward through the gap built the two pitted plains and the connecting kame terraces, enveloping and extending beyond such stagnant ice-masses as still remained. Subsequently, as it receded from the northern edge of the Carroll plain, the melting ice-sheet dumped its debris, still in ponded waters, in a confused mass of hillocks, forming the kame field north of Carroll.

RELATION OF THE CARROLL MORAINE FIELD TO THE BETHLEHEM MORAINE

The exact relation of the ice contacts and morainic ground of Carroll to those of the Bethlehem district is not yet known, but judging from the persistent northeast trend of the main lines of the Bethlehem moraine, as shown on the map (plate 13), it appears that the ice departed from the Carroll district at a somewhat earlier stage. The small and fragmentary moraine lines east of Maplewood and north of Bethlehem Junction are nearly in line with the Carroll moraine field; but time did not allow us to trace these northeastward around Beech Hill. The country is thickly wooded, swampy, and not traversed by convenient logging roads or trails. If there is any actual connection between the deposits west of Beech Hill and those east of it, a good deal of field-work will be required to determine it.

Ammonoosuc Glacier

DISCUSSION OF EVIDENCE PRESENTED BY EARLIER OBSERVERS

Inseparably connected with the problems already discussed, yet presenting elements of its own, is the question of the former existence of a local Ammonoosuc glacier. Of the several local glaciers which Professor

Hitchcock reported in New Hampshire and Vermont, this has been regarded as the most important, because it, unlike the others, appears to have moved in a direction opposite to that of the Canadian ice-sheet, namely, westward and northwestward; and its records should therefore be more easily distinguished from those of the regional ice movement. The evidence on which Hitchcock based his belief in this local glacier will now be reviewed and analyzed with brief comments.

"The eastern slope of the hill between Maplewood [northeast of Mount Agassiz] and Bethlehem Junction is thickly strewn with large boulders *of material similar to the nearest ledges.* Their position is suggestive of transportation down the Ammonoosuc from the east. As similar rocks occur as far as the Twin Mountain House, it is not unlikely that the Ammonoosuc glacier brought them there; but further study is required to demonstrate the proposition." [19]

Just how the position of these boulders at Bethlehem Junction justifies Hitchcock's preference for a distant easterly source rather than the source which he says is close at hand is not stated.

"Many large blocks of a coarser grained granite than ordinary lie upon the slope of Mount Deception, just opposite the Fabyan House, and along the turnpike for a mile easterly. These have not traveled far, having been derived from the south base of Mount Deception. One piece is 22 feet long, 14 feet high, and 10 thick. Those 6 feet in length are common. The fragments are too far removed from the mountain to have accumulated merely by gravity." [20]

The field here described lies just south of Mount Deception, directly on the southeastward path of the ice-sheet. Although no ledges outcrop through the drift, near the blocks, Hitchcock assigns the district to the Mount Deception granite area on his bedrock geology map. Here, then, as in the case of the blocks west of Bethlehem Junction, blocks admittedly of native rock are used as evidence of transportation from a foreign source. The deposit referred to is a knob and kettle moraine, a short distance east of Fabyans, consisting chiefly of sand, but well sprinkled with large blocks. Like the moraine at Bethlehem and Carroll, it appears to mark the rapid deposition of drift in ponded waters along the irregular southern margin of the ice-sheet as it retired from the Upper Ammonoosuc Valley.

"The recent clearings disclose a sharp conical moraine south of the Mount Pleasant House, perhaps 20 feet high, and very different in character from the neighboring mounds of esker and river gravel. The many large granite blocks, where the railroad approaches near the Ammonoosuc River, above Mount Pleasant and near the upper falls, are also like a local moraine." [21]

[19] Op. cit., p. 241.
[20] Op. cit., pp. 241-242.
[21] Loc. cit.

The evidence here is purely and simply the presence in the Ammonoosuc Valley of small morainic deposits. Hitchcock's description of them does not afford ground for choosing between the theory of a local valley glacier and that of an ice-sheet. In the field one finds that the latter theory is entirely satisfactory.

"In the fields east of the Twin Mountain House there are hundreds of boulders of Mount Deception granite, often 12 feet in length. . . . This is an example of materials transported westerly a distance of four miles." This evidence has been discussed on an earlier page, where the full quotation appears. The parent ledges in question lie up the hillside, a quarter of a mile northwest of the blocks, and bear striæ which were made by the southeastward movement of the Canadian ice-sheet. Moreover, the evidence from the Carroll outwash plains and kame terraces, near by, as already explained, argues against the theory of a local Ammonoosuc glacier.

"Just west of Rounseval and Colburn's sawmill, midway between the Twin and White Mountain houses, I found a large block of granite, in 1871, nearly 12 feet in diameter, and about square, closely resembling a handsome variety of granite occurring on Mount Willey and further south. A second small one exists in the neighborhood. I have never found this particular kind of granite north of the Notch in ledges, and as it occurs with the Conway granite near Mount Willey, it is probable that these blocks descended the Zealand Valley, starting from the west side of the same mountain." [22]

The value of this evidence is not easy to estimate, since Hitchcock did not describe the variety of Conway granite in question, and it can not therefore be identified, either at the alleged source on Mount Willey or in other districts of Conway granite. Hitchcock maps an area of Conway granite immediately north of the place where the boulders were reported. After seeing the mistake which he made in overlooking the ledges of granite on the hill east of Twin Mountain (discussed on page 25), one may reasonably question whether the peculiar Conway granite boulders near the Rounseval sawmill may not have come from the area of Conway granite north of that point, instead of from the southerly exposure of Conway granite on Mount Willey. To assume that the "handsome variety" observed in the boulders does not occur in the more northerly area because it has not been seen there is unwarranted. The areal geology of that wooded and drift-covered country was very imperfectly known in Hitchcock's time, as now. The real source of the boulders in question must remain in doubt.

"Other boulders, seemingly from the south, are a few of Chocorua granite from near the Crawford House, in which Professor Dana discovered grains of

[22] Loc. cit.

chrysolite. I know of no ledge to the north of their present situation from which they could have been derived, while similar ledges abound farther south."[23]

The statement as to location of these ledges and the type of rock concerned is too ambiguous to permit a later investigator to either confirm or deny the opinion which Hitchcock presents. It may be remarked, however, that since the Crawford House stands on the drainage divide between the headwaters of the Ammonoosuc and Saco (see plate 13), the theory that the drift came from the south would seem to require a local glacial movement through the Notch from sources unmentioned and unstudied on the south side of it. Without more complete and explicit statement of the evidence, serious consideration can hardly be given to it.

"Examples of transported boulders of Albany granite are more decisive of a glacial movement down the stream. From the mouth of New Zealand River nearly to Bethlehem station are numerous blocks of this granite, six feet in length. This rock is in place on the New Zealand River, but not on the Ammonoosuc. Hence the fragments must have moved down the stream (also Little River, in Carroll), and being too large for water transportation, require the agency of a glacier. Rude striæ, supposed to have been made at this period, occur near the Wing Road in the river. The boulders are found as far south as North Lisbon. I obtained a specimen there weighing about eight pounds. No search has been made for them lower down. Their location in the river and angular shape indicate transportation by a local glacier."[24]

So far as the boulders below Bethlehem Junction are concerned, the report seems to indicate that they are small enough to have been carried downstream by the river. The occurrence of blocks of this rock 6 feet long between Bethlehem Junction and the mouth of the Zealand River is a matter of which I did not feel fully convinced in the field. In sections of drift deposits beside the Ammonoosuc, below Zealand River, blocks and boulders several feet in diameter of various types of granite and gneiss are numerous, but I found none of the peculiar granite porphyry which Hitchcock called the "Albany granite." A few cobbles and plenty of well rolled pebbles of that porphyry were found in a gravelly fan at the mouth of the Zealand River, but these were obviously torrent-carried and can not be used as evidence of northward movement of a local glacier. If Professor Hitchcock is correct in his report of large blocks of Albany granite along this portion of the lower Ammonoosuc, the absence of exposures of that rock north of the river is still a debatable question, on account of the mask of drift and forest and the lack of thorough exploration.

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[23] Loc. cit.

[24] Op. cit., p. 243.

"About half a mile above Bethlehem station the valley is almost closed by a large hill of till, with some stratified layers on the outside. This eminence resembles a moraine."[25] The State highway ascends this hill just east of Bethlehem Junction. Good sections of the deposit are to be seen both by the side of the road and by the railroad. It is a rather smooth-topped mass of boulder-clay, capped on the northwest with cross-bedded sands and gravels which make low sags and swells. Instead of a terminal moraine built by a local glacier moving westward, this appears to be an imperfectly constructed moraine built at the front of an ice-sheet which moved southward. The drift composing it seems to have come from northern sources, and the striæ of the region nowhere run east and west, as a local Ammonoosuc glacier would do, but southward, in the same direction as the dispersion of stones.

Hitchcock's argument for a local glacier in the Ammonoosuc Valley closes with a brief description of recently formed landslide deposits on Little River. So far as I can see, it throws no light on the problem. As already stated, oversteepened slopes have resulted at many places in the White Mountains from regional (not local) glaciation.

In his paper of 1904 Doctor Upham reports that he saw

"characteristic narrow valley moraines only near the old White Mountain House within 20 to 30 rods north and west from it, about one mile west of the Fabyan House. These little ridges of drift, parallel and four or five in number, well strewn with boulders, rise five to ten feet above the nearly level ground, and extend from north to south, transverse to the Ammonoosuc Valley, at its northern side. Other valley moraines were looked for, but were nowhere seen, in the distance of about 6 miles eastward to the foot of the steep west side of Mount Washington, where it is ascended by the railway." [26]

The little ridges near the White Mountain House were thus accepted as evidence of Hitchcock's Ammonoosuc glacier. Observations in this district in 1915 have led me to believe, on the contrary, that the deposits mark a stage of recession of the Canadian ice-sheet. A brief description of them follows:

Immediately north and west of the White Mountain House is a smooth tract of ground, rising but slightly above the level of the adjoining intervals and occupied by a hayfield. Just west of this field, in the next piece of property, are the drift ridges described by Upham. Near the railroad an open pasture allows their peculiar forms to be plainly seen, but a few hundred yards north of the railroad second-growth forest partially conceals them, and the work of tracing their courses northward is

[25] Loc. cit.
[26] Op. cit., p. 12.

thus rendered somewhat difficult. The most conspicuous feature among them is a gracefully winding ridge which extends about north and south (magnetic) from the edge of these woods to the railway, just west of the point where this is crossed by the State highway. The crest of the ridge rises from 8 to 15 feet above the ground on either side. Although no boulders lie on it, many are scattered on the ground beside it, suggesting that it may once have had a sprinkling of blocks, like certain other mounds and ridges which lie only a few rods to the northwest of it. Much of this ridge has been cut away near the railway for use as road ballast and several fresh sections are thus exposed. In all of them the anticlinal bedding of gravels characteristic of eskers is plainly seen. In structure as well as in form, therefore, this can be recognized as marking a line of glacial drainage. Although in general it runs perpendicular to the Ammonoosuc Valley—if the trend west of the White Mountain House is considered—it is equally true that it nearly follows the trend of the valley above that point, which is nearly north and south. Like the larger esker at the Twin Mountain House, in its trend and relation to main and tributary valleys, this little esker appears to mark a short stretch in the course of a river which flowed southward through the melting ice-sheet into the ponded waters of the Ammonoosuc. About 200 yards north of the railway, near the edge of the woods, the esker is joined by shorter and less regular hummocks, on whose surfaces angular blocks are numerous. These are continued northward, in the half-lumbered woods up the hill-side, by linear mounds of drift of less perfect form. How much farther they extend I am not able to say. It is evident, however, both from the form and the structure of the deposits and their relation to the valley, that they are essentially a line of kames and not a recessional moraine. On the steep hillside, about a mile east of the White Mountain House, clearings reveal several other ridges, similar in appearance to this one. They descend obliquely to the Ammonoosuc Valley. Some of them may be of morainic character, marking the margin of the ice against the hill-side, like those noted one mile east of Wing Road. If so, their north-east-southwest trend requires an ice-front which was convex southward and not northward; in other words, a tongue of the Canadian ice-sheet.

CONCLUSIONS REGARDING LOCAL GLACIATION IN THE AMMONOOSUC VALLEY

Observations in the Ammonoosuc Valley, between Bethlehem Junction and Bretton Woods, appear to me, therefore, to fail to indicate the existence there at any time of a local Ammonoosuc glacier for the following reasons:

(1) The valley follows an east-west course, and the local glacier should have done the same. There are no striæ known except the north-south striæ, which all observers, including Hitchcock, have assigned to the continental ice-sheet.

(2) The boulders of gneiss on the hill west of Bethlehem Junction and of Mount Deception granite east of the Fabyan House resemble the nearest ledges, including ledges which are known to occur short distances north and west of them.

(3) The boulders of granite reported to have moved westward from Mount Deception to the Twin Mountain House can be referred to ledges on the hillside immediately northwest of their resting places.

(4) The boulders of Albany granite reported by Hitchcock might easily have come from unknown sources north of the Ammonoosuc Valley.

(5) The patches of morainic ground noted in the valley are not so formed nor so related to the valley as to suggest the margin of a local glacier resting against their up-valley sides.

(6) The "local valley moraines" near the White Mountain House, in particular, lack the form and relationship to topography which such moraines would possess, but prove to be a local kame and esker series, presumably left by the Canadian ice-sheet.

Limited Occurrence of Cirques in the White Mountains

The foregoing evidence against local glaciation, both in the Ammonoosuc Valley and in the ravines on the north side of Mounts Lafayette and Garfield during the closing stage of the Glacial period, is in accord with observations on the Mount Washington Range in 1912.[27] Although well developed cirque sculpture was found in several of the Mount Washington ravines, notably in Kings, Huntingtons, and Tuckermans ravines and the Great Gulf, index forms of local glaciation were absent beyond the mouths of these ravines and entirely absent in others which head on the same slopes; and, so far as distant observation could be trusted, no signs of glaciation were evident on the Carter Range, whose summits approximate 5,000 feet altitude. The inference was drawn, therefore, in 1912, that the local glaciers were not at any time extensive enough to reach beyond the foot of the highest ranges of the region, and that probably they were confined to the heads of the highest and otherwise most favorably situated ravines. Reasons were advanced, also, for the view that the local glaciation occurred principally, if not wholly, before the

[27] J. W. Goldthwait: Glacial cirques near Mount Washington. Amer. Jour. Science, vol. xxxv, 1913, pp. 1-19. Following the trail of ice-sheet and valley glacier on the Presidential Range. Appalachia, 1913.

last regional glaciation. The absence of local frontal and recessional moraines from the ground at and just above the lower limits of the glacier-carved valleys, whose lofty headwalls must have furnished an immense bulk of debris, *many times as great as that which now lies on the floor of the troughs and cirques,* and the presence instead of ground moraine from the northwest was taken to indicate that the southeastward advance of ice from Canada, following the period or stage of local glaciers, had overwhelmed these and had blotted out their moraines, without, however, destroying the great headwalls which they had carved out or the troughlike form of their trunks. It was noted also that on the headwall of the Ravine of the Castles, which faces northwestward, on the north side of Mount Jefferson, projecting angles of the ledge were worn into roches moutonnées forms by a southeastward movement of the ice *uphill* against it, overriding the crest of the range at its head. It was reported that the southeast side of the Great Gulf appeared to have suffered considerable abrasion from ice passing over it during the regional glaciation. The conclusions reached regarding local glaciation thus differed from those of Agassiz, Hitchcock, and Upham in the White Mountains and of Tarr, at Katahdin, in two respects: (*a*) the local glaciers were believed to be of very limited extent, and (*b*) they were believed to be of earlier date than the last glaciation by the Canadian ice-sheet. A few additional observations made in 1915 on the Mount Washington Range, Franconia Mountains, and Mount Moosilauke are reported in the few pages which follow, inasmuch as they extend the limits of the district which has been examined for signs of extinct local glaciers.

A brief visit to the southern peaks of the Mount Washington Range, giving me my first view of the ravines which flank them, and of the ravines directly west of Mount Washington, satisfied me, as the generalized contour lines of the Geological Survey quadrangles had not done, that a limited amount of cirque cutting has taken place on this part of the range also. It is seen in the development of curved cliffs at or just below the heads of Burt, Ammonoosuc, and Abenaki ravines, southwest of Mount Washington, and of certain ravines tributary to Oakes Gulf. In none of these is the bowl-shaped form complete. No such perfect 1,000-foot headwalls are displayed as those which distinguish Kings, Huntingtons, and Tuckermans ravines and the Great Gulf, and below the cliffs there is no abrupt flattening into a floor or basin bottom. The line between the curved cliffs and the crest of the range is far less definite here, also, than in the eastern and northern ravines, for the southern peaks are steep-sided projections along a relatively narrow ridge, and there are no extensive "lawns" or gently graded slopes to suggest a "bis-

cuit-cut" upland like that on the northern half of the range. Whether the amount of cliff cutting requires the occupancy of these ravines by actual glaciers or whether it may be attributed to nivation alone is a question which it would be unsafe to settle on mere topographic evidence; but in the light of the very pronounced glacial sculpture on the eastern and northern sides of Mount Washington, the presence of small glaciers at the ravine heads named above seems not unlikely.

A very limited development of valley glaciers is indicated also by the absence of cirque form in the ravines on the north side of the Franconia Mountains. The broad, steep-sided valley which heads between Mount Garfield and the Twin Mountains and which is drained by the easternmost branch of Gale River appears somewhat troughlike, as seen from the north, with spurs which show fairly distinct shoulders. I was not able to satisfy myself, from the top of Mount Garfield, that this ravine has a cirquelike head, and there are no contour maps which afford good detail. On closer study, however, this might prove to belong in the class with Kings Ravine and the Great Gulf. The White Cross Ravine, as reported on a preceding page, appears to possess only ordinary torrent-worn slopes. Its head is steep, but there is no semicircular headwall, and the descent is rapid and uniform along a V-shaped gorge. Ravines which occupy the western side of Lafayette and Lincoln and which descend toward the Flume House are much more bowl-like at their heads; yet they, too, lack the full strength of form which characterizes the Mount Washington cirques. It is doubtful, therefore, if there was any considerable development of valley glaciers on the Franconia Mountains during the period of local snowfields. The summits of the Franconia Mountains south of Lafayette are peaked like it and of inferior altitude, so the conditions for local snowfields on them are less favorable than on that mountain.

A more cirquelike form was found in Jobildunk Ravine, on the eastern side of Mount Moosilauke (4,810 feet). We camped on its floor, climbed its side walls and headwall, and looked down into it from the trail which ends on its brink, about three-quarters of a mile east of the Tip Top House. The ravine is a broad trough, heading in a complete semicircular cliff, the height of which is at least 300 feet. Above the cliff there is a fairly steep upper extension of the rim, in a curved, block-strewn slope of the mountain, much as the cliff at the head of Tuckermans Ravine has a steep, funnel-like slope of ledge and talus on its brink; only in the case of Mount Moosilauke the slope is clothed with scrub forest. At the foot of the headwall of Jobildunk Ravine blocks lie massed in great apron-like slopes on the floor, partly filling the first quarter mile of its bowl-like head; but beyond that point the floor is nearly flat, descending without

noticeable change of grade or inequality of surface. A small brook which heads in a ribbon cascade on the headwall courses slowly along the floor. There is no pond here like Hermit Lake, in Tuckermans Ravine, or Spaulding Lake, in the Great Gulf. It is hard to imagine a local glacier abandoning this ravine at the close of the Glacial period and leaving its floor so perfectly free from morainic ridges or knolls. The cirque cutting evidently antedates the last regional glaciation. The block pile at the head of Jobildunk Ravine, like those in the Mount Washington ravines, appears to be freshly quarried englacial drift, dropped by the ice-sheet, together with rockfall debris of the period of deglaciation.

One is disinclined to accept Jobildunk Ravine as an ancient cirque, because it exceeds in size most of the Mount Washington ravines, although it lies on the flank of a mountain only 4,810 feet high, and because the ravines around Mount Lafayette (5,269), as already stated, seem to be little altered, if at all, by local glaciers. Two factors may perhaps reconcile the apparent inconsistency: (*a*) The area above 4,000 feet on Mount Moosilauke, though somewhat smaller, is much wider in an east-west direction than that on the Lafayette Range. The chance for snow to collect in the ravines on the leeward (eastern) side of the mountain is therefore greater on Moosilauke than on Lafayette. (*b*) The development of a headwall depends largely on the condition of jointing at the head of a ravine. It is possible that the quarrying out of the rock-masses from the head of Jobildunk Ravine was more favored by the attitude and number of joints there than on the side of Mount Lafayette. These factors might compensate for the difference in height of Lafayette and Moosilauke, which, after all, is only about 450 feet.

The ravine on the northwest side of Moosilauke, which is skirted by the Benton trail, is wider and rather funnel-shaped at its head, but lacks the U-shaped cross-section and the steep headwall of Jobildunk Ravine. So far as known, therefore, the local glaciation of Mount Moosilauke seems to have been limited to the single glacier on its eastern side.

From these scattered, yet related, observations it appears probable, as in 1912, that the local alpine glaciers of the White Mountains were very short, occupying only a few of the more favorably situated ravines, and that they completed the development of cirque forms before the last or southeastward passage of the ice-sheet over the region.

Conclusion

Assembling the conclusions reached through field-work on and around the Bethlehem moraine, the Carroll outwash deposits, the special features of the Ammonoosuc Valley, and the ravines on the neighboring summits,

as well as those on the Mount Washington Range and Mount Moosilauke, we may resolve them into the following general propositions:

(1) There was a time in the Pleistocene period, *prior to* the last advance of the North American ice-sheet over New England, when local snowfields on the higher ranges supported small, short glaciers of the alpine type. These were probably confined to the sides of peaks which exceed 4,500 feet altitude, and only then in favorable situations. This condition may have lasted merely during the early stage of the last Glacial epoch or during a part or the whole of one or more earlier epochs of glaciation. It sufficed, in any case, for the carving out of well defined cirques.

(2) During the stage of maximum glaciation of the last Glacial epoch the ice-sheet, whose center was in Canada, moved across the White Mountain region from northwest to southeast. It obliterated all local valley moraines, but spared the cirque form of the ravine heads.

(3) When at the close of the last Glacial epoch the ice-sheet melted away from northern New England, it departed from the White Mountains without leaving any local glaciers—much less a local ice-cap—in them. It retired toward the northwest, building at least one strong line of recessional moraine in the Ammonoosuc Valley, where ponded waters caught an immense mass of stratified drift.

Finally, it is interesting to find that Professor Hitchcock read a paper on "Terminal moraines in New England" at the Rochester meeting of the American Association for the Advancement of Science, in 1892, in which he undertook to sketch the outline of the continental ice-sheet at several stages of its retreat from northern New England, by means of belts of kames, outwash deposits, and other features associated with an ice-front. These lines, he reported, run somewhat north of east. "There may be relics of another line," he said, "along the principal White Mountains, as indicated by kames near Littleton and moraines at Bethlehem Hollow and Carroll."[28] While it is not clear how to reconcile this interpretation with his views regarding local glaciers, and an Ammonoosuc glacier in particular, the suggestion is no less prophetic.

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[28] C. H. Hitchcock: Terminal moraines in New England. Proc. Amer. Assoc. Adv. Sci., vol. 41, 1892, pp. 173-175.

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PLEISTOCENE DRAINAGE CHANGES IN WESTERN NORTH DAKOTA [1]

BY A. G. LEONARD

(*Presented before the Society December 29, 1915*)

CONTENTS

INTRODUCTION

The continental ice-sheet produced important drainage changes in western North Dakota. Its effects are particularly well shown in the case of the Missouri, the Yellowstone, and the Little Missouri rivers, since all these streams were forced to seek new channels. The region was three times invaded by the ice-sheet—the later Wisconsin, earlier Wisconsin, and an earlier invasion, which was probably Kansan or possibly sub-Aftonian—but it was the earlier, or pre-Wisconsin, invasion which caused most of the changes. The southerly course of the Missouri River below old Fort Stevenson has been attributed to the latest or later Wisconsin ice-sheet, but evidence is here presented that the valley, at least in North Dakota, is preglacial, using the term preglacial to mean older than the oldest ice-invasion of this region—it may mean either pre-Kansan or pre-sub-Aftonian.

AGE OF THE MISSOURI RIVER VALLEY

As long ago as 1868 Gen. G. K. Warren made the statement that the present course of the Missouri River was determined by the edge of the

[1] Manuscript received by the Secretary of the Society December 20, 1915.

ice-sheet: "There, then, on that limit a river must have been formed to carry away the melting water from the glacier, and this limit was the Missouri River, and that was the river formed thereby." [2]

Todd, in 1884, stated his belief that the Missouri River formerly flowed east or northeast, either to the present James or to the Mouse River.[3] In a later paper he elaborates this view and gives reasons for his theory that the river flowed northeast to the Mouse Valley.[4] Todd believes that there is evidence that the Heart and Cannon Ball rivers once flowed on east to the James River, and that the valley of Snake Creek is the preglacial valley of the Missouri River. The valley of Snake Creek is no larger than the valleys of other tributaries entering the Missouri above this point, and the notch in the east front of the divide north of Fort Stevenson, which is shown on some maps, does not exist in reality, and there is no evidence of any preglacial valley here. The valley of Long Lake Creek could hardly have been the eastward extension of the Cannon Ball River Valley, since its lower course is not opposite the mouth of the latter stream, but joins the Missouri four miles to the north. There is no reason for believing that the Knife River ever joined the Missouri near Fort Stevenson, and the lower valley of this stream has every appearance of great age, having a broad flood-plain and gentle slopes. It is clearly a preglacial valley. The Heart River is thus the only important tributary of the Missouri which might have continued eastward to the James River if the valley of Apple Creek, which has its mouth just opposite the Heart, is an indication of this. But Apple Creek is readily accounted for as a preglacial tributary of the Missouri and one of the chief outlets for the glacial waters when the ice-margin occupied the position marked by the Altamont moraine. Its valley is largely filled with glacial outwash from the moraine.

There is abundant evidence that the Missouri Valley below the mouth of Snake Creek is preglacial, and that the river was not forced by the ice-sheet to take its present southerly course through North Dakota. This evidence is based on the presence of glacial boulders on the valley bottom and at many points on a terrace representing a former flood-plain of the Missouri. Boulders have been encountered in two wells in Bismarck at a depth of 125 feet below the surface or 80 feet below river level. These wells are near the edge of the terrace bordering the Missouri Valley at Bismarck, and since the boulders rest on the bedrock they indicate that the valley was excavated to this depth prior to the Glacial period. In

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[2] Annual Report, Chief of Engineers, U. S. Army, for 1868, pp. 307-314.
[3] Proc. Am. Assoc. Adv. Sci., vol. 33, 1884, pp. 381-392.
[4] Science, vol. 39, 1914, pp. 265-274.

several borings made for the Northern Pacific Railroad previous to the building of its bridge across the river at Bismarck, from 70 to 80 feet of silt and gravel were passed through before reaching the bedrock, and in

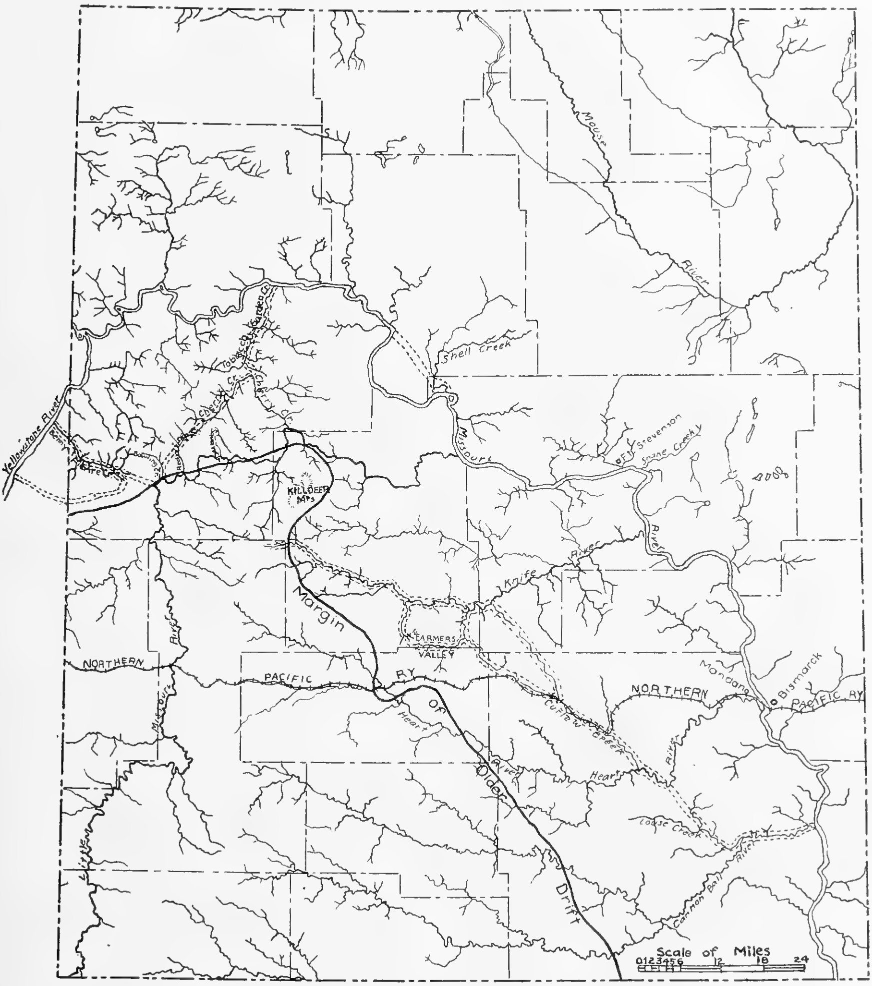

FIGURE 1.—*Map showing old Pleistocene Valleys of western North Dakota*

one boring a boulder was struck at a depth of about 50 feet below the river bed.

On the west side of the Missouri Valley, between Mandan and the mouth of the Knife River, there is a well developed terrace which in places is a mile and more wide. This terrace has an elevation of 55 to 60

above the river and the upper portion of it is in many places composed of glacial gravel and good-sized boulders. A railroad cut in this terrace a mile northeast of Mandan, near the cemetery, shows the following section:

	Feet	Inches
Soil	2–3	....
Boulders and gravel	5–9	....
Sand, finely laminated, with several thin layers of gravel	2–5	....
Boulders and pebbles	...	6–12
Lance beds, exposed above railroad track	15	....

In another cut less than one-quarter of a mile south a bed of boulders, many of them several feet in diameter, mixed with gravel and resting on the Lance beds, extends a distance of at least 100 yards along the railroad.

Several miles south of Price the upper part of the terrace is composed of boulders and coarse gravel, the deposit having a thickness of 5 to 6 feet. Between Sawyer and Price the terrace is finely developed and is covered in some places by a layer of gravel and boulders; in other places by unstratified glacial drift or boulder-clay. In the vicinity of Hensler the Missouri Valley is several miles wide, and here, as well as in other places, numbers of low, rounded drift hills, covered with numerous boulders, rest on the valley floor. Some of the railroad cuts show the boulder-clay to be 30 to 40 feet thick.

Before the time of the earlier ice-invasion, when the ice-sheet advanced 40 to 50 miles beyond the Missouri River, that stream must have flowed in its present broad, terraced valley, and on the floor of this valley the glacier deposited the boulders, gravel, and till so well exposed at many points. These deposits, shown in the railroad cuts of the terrace, lie about 40 feet above the ordinary stage of the river and vary considerably in thickness.

C. M. Bauer believes that during late Tertiary time the Missouri River flowed northeast from Poplar, Montana, and that its waters finally reached Hudson Bay.[5] Also that the Yellowstone flowed northward from Williston by way of the valley of Muddy Creek. But it has been shown that the present Missouri Valley in North Dakota is preglacial, and it is doubtful whether the river in late Tertiary time had a course differing from its present one. Additional evidence that the present valley is preglacial, and that the trench of the river was excavated to its present depth at the time of the earlier ice-invasion, is shown by the boulder bed less than half a mile below the mouth of Tobacco Garden Creek. This bed of

[5] C. M. Bauer: "A sketch of the late Tertiary history of the Upper Missouri River." Jour. Geol., vol. xxiii (1915), pp. 52-58.

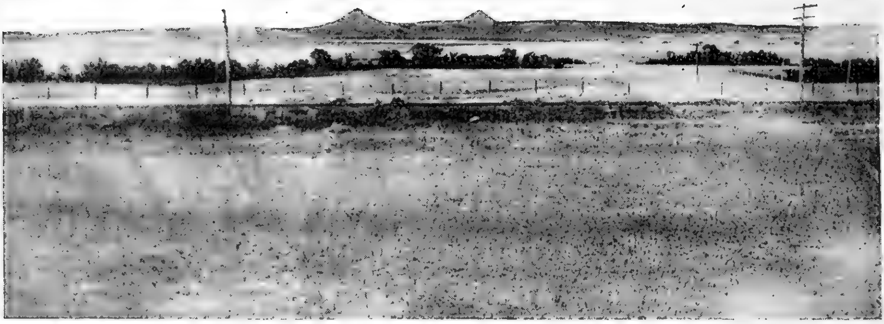

FIGURE 1.—LOOKING ACROSS THE OLD PLEISTOCENE VALLEY OF THE MISSOURI AND YELLOWSTONE RIVERS NEAR GLEN ULLIN, NORTHWESTERN MORTON COUNTY, NORTH DAKOTA.

FIGURE 2.—BROAD PLEISTOCENE VALLEY OF THE YELLOWSTONE RIVER, LOOKING EAST THROUGH THE VALLEY TOWARD THE LITTLE MISSOURI RIVER, WESTERN MCKENZIE COUNTY, NORTH DAKOTA.

OLD PLEISTOCENE VALLEYS IN WESTERN NORTH DAKOTA

boulders, which lies just above river level, is at least 12 to 14 feet thick and extends along the water's edge for a distance of 100 yards, while scattered boulders and ferruginous gravel occur at intervals for another 200 yards. Overlying the boulders are 15 feet of gravel. While some of the boulders of this deposit may have been brought here by floating ice, it is probable that most of the deposit was left here by the pre-Wisconsin ice-sheet when it advanced south of the river. The finer materials of the drift, if they were ever present, have been carried away, leaving the gravel and boulders.

Pleistocene Valley of Missouri and Yellowstone Rivers

But while the Missouri River probably occupied its present valley for a considerable time prior to the Glacial period, the ice-sheet, when it invaded the region, blocked the valleys of both the Missouri and Yellowstone rivers and also the preglacial valley of the Little Missouri, forcing these streams to seek new channels. Lakes were formed in the valleys of the Yellowstone and Little Missouri rivers, the water rising until it overflowed the divide between the latter and the Knife River south of the Killdeer Mountains. The combined waters of the three rivers flowed east across Dunn County and southeast across Morton to the mouth of the Cannon Ball River. The valley thus formed crosses the divide between the Knife and Heart rivers and also that between the Heart and Cannon Ball. The length of this Pleistocene valley of the Yellowstone and Missouri rivers from the head of the Knife to the mouth of the Cannon Ball is 155 miles. It is followed for 30 miles by the Northern Pacific Railroad between Almont and Hebron, this portion of the valley being today occupied by Curlew Creek (figure 1, plate 14). The Heart River follows the valley for 6 to 8 miles below the mouth of Curlew Creek, and the broad depression continues its southeasterly course through the divide to the Cannon Ball, being followed for many miles by Louse Creek, a tributary of the Cannon Ball.

Two broad valleys connect the Knife River Valley with that of Curlew Creek. One enters the latter valley between 3 and 4 miles below Glen Ullin and is followed by the northward flowing Elm Creek throughout a portion of its extent. Between the latter and the tributary of Curlew Creek the valley bottom is occupied in part by a hay marsh. The other valley, which joins that of Curlew Creek just below Hebron, is known as Farmers Valley and extends to the head of Deep Creek, a tributary of Knife River.

It will be noted that the Knife, Heart, and Cannon Ball rivers, together with several of their tributaries, now occupy parts of this old Pleistocene valley of the Missouri and Yellowstone rivers. The valley is clearly much too large to have been formed by several of the streams which today flow through it, such as Curlew, Elm, or Louse creeks, and some portions now have no stream. Throughout much of its course the old valley has a broad, flat bottom one-half to one mile and more wide, with gently sloping sides.

Pleistocene Valleys of the Yellowstone River

The lower 50 miles of the Yellowstone Valley was blocked with ice during the Glacial period and the river was forced to seek a new channel. Its waters flowed east to the valley of the Little Missouri and formed at least two broad, flat-bottomed valleys connecting these streams. The most northerly of these old valleys, which is 28 miles long, is now occupied by the northwestward flowing Benny Pierre Creek, a tributary of the Yellowstone, and by the eastward flowing Hay Draw Creek, a tributary of the Little Missouri (figure 2, plate 14).

The second valley has a northeasterly course, is about 32 miles long, and joins the first about 10 miles above its junction with the Little Missouri. That portion of the Benny Pierre-Hay Draw Valley floor which forms the low, flat, almost imperceptible divide between the Yellowstone and Little Missouri drainage systems has an elevation of 185 feet above the latter river, or about 2,209 feet above sealevel. The valley is bordered on either side by high, steep bluffs and the level plain forming its broad bottom is nearly a mile wide. This great trench was clearly occupied at one time by a stream many times larger than those now having possession of it.

Preglacial Valley of the Little Missouri River

The Little Missouri, as well as the Yellowstone and Missouri rivers, was forced out of its preglacial valley by the ice-sheet. The lower 55 miles of this valley was filled with ice, so that a lake was formed back of the glacial barrier, the water rising and overflowing to the east by way of the old valley previously described as occupied by the Missouri and Yellowstone rivers during the Pleistocene period.

The abandoned valley of the preglacial Little Missouri was first men-

tioned by Wilder,[6] who saw one end of it in 1903, but its course was not explored.

During the summer of 1914 this old valley was mapped in detail by the writer and a line of levels was run from the south edge of the Ray quadrangle to the Little Missouri River. The valley extends from the mouth of Bowling Creek north and east to the Missouri River at the mouth of Tobacco Garden Creek, a distance measured along the axis of the valley of 55 miles. Its bottom varies in width from half a mile to one and three-quarters miles and throughout much of its course it is a mile or more wide.

Two very low and inconspicuous divides are present in this valley, one between Tobacco Garden and Cherry creeks and another between Cherry and Redwing creeks. The former is between 3 and 4 miles north of Schafer, where the divide is less than 20 feet above Cherry Creek. Even more flat is the divide separating the headwaters of Cherry from those of Redwing Creek, which is located about two miles south of Elsworth. For a distance of 3 to 4 miles along the valley floor the elevation does not vary more than 4 or 5 feet, and so flat is this interstream area in the old valley that the water does not run off after a rain, but stands on the surface until it sinks into the ground or evaporates.

The present divide between Redwing and Bowling creeks constitutes the highest point in the old river valley. Its elevation is 2,191 feet above sealevel, or 177 feet above the Little Missouri at the mouth of Bowling Creek. In that portion now occupied by Cherry Creek the average slope of the valley floor is 7.4 feet per mile for a distance of 20 miles, while in that portion occupied by Tobacco Garden Creek the slope averages 5.5 feet per mile.

Abnormal Drainage Features of Little Missouri Tributaries

The upper valleys of both Squaw and Redwing creeks open out into this preglacial valley of the Little Missouri, so that the floors of these valleys tributary to the Little Missouri are continuous with the broad flats of Cherry Creek. The explanation of this peculiarity, in the case of Redwing Creek, is found in the fact that this youthful and vigorous stream, with a fall of 23 feet per mile, has worked its way back by headward erosion and taken possession of a portion of the flats forming the

[6] The lignite of North Dakota and its relation to irrigation. Water Supply and Irrigation Paper No. 117, U. S. Geol. Surv., p. 43; also Third Biennial Report, North Dakota Geol. Surv., map, p. 16.

old valley floor, so that now the tributaries of Redwing Creek meander over the flats in shallow trenches cut in the valley plain.

That portion of Squaw Creek above the sharp bend was formerly a tributary of the Little Missouri when it occupied the old valley. But in postglacial time the young and vigorous Squaw Creek, which is now tributary to the Little Missouri of today, with a fall of about 22 feet per mile, worked its way back until it captured the northward flowing tributary of the preglacial river and diverted the waters to the south, thus forming the sharp bend in the present course of Squaw Creek.

The abnormal features of the Cherry Creek drainage are even more striking than those of Redwing Creek. The upper valley from Elsworth to the bend several miles north of Schafer is broad, the valley floor being in many places from one to one and one-half miles wide; the side slopes are for the most part gentle, and the rather numerous tributaries enter by broad, flat-bottomed valleys. In contrast to this the lower valley is comparatively narrow, from one-quarter to one-half mile wide, and the side walls are quite steep. In its upper course the creek has an average fall of 7.4 feet per mile, while below the bend the average fall is almost 10 feet per mile. The normal stream has its broad flats along its lower course, where the fall is also less than in the upper portions of its valley. The explanation for the abnormal features of Cherry Creek is clearly to be found in the fact that above the bend near Schafer it follows the old preglacial valley of the Little Missouri River, while below the bend it flows in a much younger postglacial valley. After the Little Missouri had been forced by the ice-sheet from its former valley and had cut its present trench, a tributary developed and extended itself by headward erosion, forming the present lower valley of Cherry Creek. This vigorous young stream worked back until it reached the preglacial valley of the Little Missouri and captured the upper portion of the creek flowing through it, diverting it to its present southeasterly course below the bend where the piracy took place. With such a development the Cherry Creek drainage would possess the abnormal features mentioned above.

Evidence of postglacial Age of Lower Little Missouri Valley

When the Little Missouri River was forced by the ice-sheet to seek a new channel, it probably flowed for a time through the Pleistocene valley of the Missouri and Yellowstone rivers, previously described. But later it took an easterly course and formed its present postglacial valley, which extends from the mouth of Bowling Creek to the Missouri River, a distance of 100 miles. There is abundant evidence that this lower valley of

the Little Missouri is much younger than the portion above the mouth of Bowling Creek, and that it has been formed since the ice-invasion of the Glacial period. The following are some of the reasons for believing it to be postglacial, or at least post-Kansan:

1. The great majority of the tributaries of the lower Little Missouri below Bowling Creek are short—much shorter than those above. Most of them are not over two or three miles in length, while the tributaries of the river for 60 miles above Bowling Creek are from four to eight times as long, since they have had a much longer time to lengthen by headward erosion.

2. Closely connected with the length of the tributaries is the width of the badlands, which are formed by the erosion of the Little Missouri River and the streams flowing into it. Below Bowling Creek the badlands in most places are not over five to seven miles wide, at some points extending back only two or three miles from the river on either side, while along the river above Bowling Creek the belt of badlands has a width of 15 to 25 miles.

3. One of the conspicuous features of the Little Missouri Valley in Billings County and for a few miles of its course in southern McKenzie County are the high, broad flats or terraces on one or both sides of the river. They have an elevation ranging from 240 feet at the south to nearly 300 feet above the river at the north and are one to two miles and over in width. They were undoubtedly formed prior to the Glacial period. These high terraces are wholly absent from the lower valley, which would seem to indicate that this portion is more recent and was formed since the region was elevated, so that the rejuvenated river cut its inner valley several hundred feet below the floor of its earlier one.

4. The fact that the Little Missouri River leaves its preglacial valley and turns east at a point which coincides closely with the southern boundary of the ice-sheet, and that for over 40 miles the new valley follows quite closely the former ice-sheet margin, suggests that the latter governed to some extent at least the location of the lower valley of that river. The old valley was blocked with ice as far south as the point where the Little Missouri abandons it, and the waters, when forced to seek a new channel, eventually made their way east not far from the edge of this ice-sheet, and the river thus cut its valley along this eastward course.

5. The Killdeer Mountains, in northwestern Dunn County, are flat-topped buttes or mesas, rising from 500 to 650 feet above the surrounding upland plain and nearly 1,200 feet above the Little Missouri River. They lie less than six miles south of the latter, and it does not appear

probable that they would have persisted and survived the rapid erosion to which they are subjected by the tributaries of the Little Missouri if they had long been in such close proximity to that stream. Had the latter occupied its lower valley longer than postglacial time, it is likely that the Killdeer Mountains would long since have been swept away by erosion. T. T. Quirke, in an unpublished paper, shows that the peculiar topographic features of the Killdeer Mountains are probably caused by the change in the course of the Little Missouri when it abandoned its preglacial valley.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ALEXANDRIAN ROCKS OF NORTHEASTERN ILLINOIS AND EASTERN WISCONSIN [1]

BY T. E. SAVAGE

(Presented before the Paleontological Society December 30, 1914)

CONTENTS

INTRODUCTION

The Silurian rocks of northeastern Illinois and eastern Wisconsin occur over a belt 350 miles long and from 20 or less to 50 miles wide, extending from below Kankakee, Illinois, northward to the extremity of Green Bay Peninsula, in Wisconsin. This area is on the east side of the La Salle anticline and the highland of central Wisconsin, away from which the strata dip gently toward the east; so that the older Silurian rocks reach the surface at intervals only along the west border.

ALEXANDRIAN ROCKS AND SECTIONS OF NORTHEASTERN ILLINOIS

The most southern exposure of Alexandrian rocks in this region is in the banks of Horse Creek, 1½ miles east of the town of Essex and about

[1] Manuscript received by the Secretary of the Geological Society November 27, 1915.

14 miles west of Kankakee. These strata consist of a thickness of 12 to 15 feet of brown magnesian limestone, in layers 3 to 6 inches thick, that are now known to belong to the Edgewood formation as developed in southwestern Illinois and eastern Missouri. Above the Edgewood limestone near Essex are a few feet of brown dolomite that contains silicified shells of a pentameroid described by Foerste[2] as *Platymerella manniensis,* and which has been considered the basal portion of the Sexton Creek limestone in Illinois.

Less than 10 miles northeast of the outcrop near Essex and about an equal distance southeast of Wilmington, Illinois, an excellent section of Alexandrian strata is exposed in the north bank of Kankakee River. At this place typical Maquoketa shale is immediately overlain by a bed of reddish-brown iron oolite, 3 or 4 feet thick, which is considered the youngest member of the Maquoketa series in this region. Overlying the iron oolite in apparent unconformity are 4 to 6 feet of brown magnesian limestone belonging to the Edgewood formation. This limestone is succeeded by about 20 feet of hard gray to brown limestone, in layers 6 to 18 inches thick, which represent the Sexton Creek limestone as formerly defined. The basal part of this limestone, as elsewhere in Illinois, contains many shells of *Platymerella manniensis.* A zone 15 to 18 feet above the base of the formation also contains numerous fossils, the most significant of which are *Rhinopora,* near *verrucosa; Stricklandinia triplesiana; Stricklandinia,* somewhat resembling *S. davidsoni* Billings, described in this paper as *S. pyriformis;* another species related to *S. salteri* Billings, and *Triplecia,* near *insularis* var. *anticostiensis.*

Fifteen miles north of the exposure on Kankakee River strata corresponding to the Edgewood and Sexton Creek limestones are exposed in the banks of Desplaines River, 1½ to 3 miles south of Channahon, in Will County. A section of the strata as now known in this vicinity is given below:

Section of Strata exposed 3 Miles south of Channahon

	Feet
Edgewood limestone.	
3. Limestone, gray, crystalline, the lower part containing such typical Edgewood fossils as *Lyellia thebesensis, Atrypa præmarginalis, Dalmanella edgewoodensis, Camarotœchia ? concinna, Rhynchotreta thebesensis,* and *Whitfieldella ovoides*	11
2. Limestone, brown; corresponding in part to the limestone formerly described in the original Channahon section	10
Maquoketa shale.	
1. Shale, bluish, plastic	8

[2] Aug. F. Foerste: Bulletin of the Denison University, vol. xiv, no. 6, p. 70, April, 1909.

A short distance south of the above exposure the strata containing *Platymerella manniensis* outcrop at a level only a few feet higher than the top of number 3 of the above section. Exposures of limestone equivalent to some horizon of the Sexton Creek formation are numerous over an area several square miles in extent between Channahon and Wilmington, where the covering of Pleistocene deposits is thin.

About 22 miles north of Channahon limestones corresponding in age to the Edgewood and Sexton Creek formations are exposed in the banks of Waubansia Creek, in the vicinity of Oswego, where they have quite a similar development and contain similar fossils to those along the Desplaines River.

North of Batavia limestone of Sexton Creek age outcrops in several places along the Fox River in the vicinity of Geneva, Saint Charles, and Elgin. A representative section of the strata exposed in the quarry 2 miles south of Elgin is as follows:

Section of Strata exposed in the Quarry 2 Miles south of Elgin

	Feet
Sexton Creek limestone.	
3. Limestone, yellow, dolomitic, weathering into layers 2 to 4 inches thick	4½
2. Limestone, gray, appearing massive in the ledge, but weathering into thin layers	17
1. Limestone, gray, with a number of chert bands near the middle part	15

Borings on the floor of the quarry reached the top of the Maquoketa shale at a depth of about 6 feet. No Edgewood limestone is present at this place, nor is it known in northeastern Illinois north of Oswego.

A zone in the upper part of the quarry exposure at Elgin, number 3 of the last section, contains numerous casts of shells of several species of Stricklandinia, and corresponds to the horizon of Stricklandinia in the upper part of the exposure along Kankakee River, and to the Stricklandinia zone exposed at Hamburg, in Calhoun County, Illinois. The species include *S. cf. triplesiana* and forms related to the Anticosti species *S. davidsoni, S. brevis, S. lirata,* and *S. salteri,* besides the fossils *Rhinopora* near *verrucosa, Dinobolus* sp., *Leptæna rhomboidalis, Schuchertella hanoverensis, Plectambonites transversalis* var., *Dalmanella elegantula, Orthis flabellites, Platystrophia daytonensis, Pentamerus oblongus, Cyclonema daytonensis,* and *Illænus daytonensis.*

North of Elgin to the Wisconsin State line the western border of the area of Silurian limestone is covered so deeply with glacial drift that no outcrops of Alexandrian strata are known.

Alexandrian Strata in Wisconsin

GENERAL STATEMENT

The oldest division of the Silurian limestone in Wisconsin was referred to by Chamberlin[3] under the name "Mayville beds" and has a thickness of 100 to 175 or more feet. The present studies have shown that this lowest division of the Silurian rocks of Wisconsin corresponds in time to some portion of the Alexandrian series of Illinois and Missouri and to some part of the Becsie River formation of Anticosti Island.

DESCRIPTION OF SECTIONS

Almost the entire thickness of the Mayville limestone is exposed in an abandoned quarry 3 miles south of the town of Mayville. A detailed section of the rocks exposed in this quarry is given below:

Section of Mayville Limestone exposed in a Quarry 3 Miles south of Mayville

	Feet
5. Dolomite, yellowish gray, vesicular, in layers 2 to 6 feet thick, which contain very numerous casts and molds of shells of *Virgiana barrandei* var. *mayvillensis*	21
4. Dolomite, hard, yellowish gray, with many irregular cavities and a few casts of shells of *Virgiana barrandei* var. *mayvillensis*	10
3. Dolomite, massive, hard, crystalline, in layers 4 to 6 feet thick	33
2. Dolomite, yellowish gray, fine-grained, in layers 4 to 16 inches thick	32
1. Dolomite, hard, crystalline, in rather thick layers having numerous irregular cavities	22

The upper 12 to 20 feet of the Mayville beds everywhere contain numerous casts of shells of *Virgiana barrandei* var., which serve as an excellent marker of this horizon in eastern Wisconsin.

In the large quarry 4 miles south of Mayville the zone of *Virgiana barrandei* var. occurs about 50 feet above the base, and a drilling penetrated 90 feet of dolomite below the floor of the quarry without reaching Maquoketa shale, indicating a thickness of at least 140 feet of Mayville limestone below the Virgiana zone.

The relation of the Mayville limestone to the older strata of this region is well shown in the quarry face of the old iron-ore pit in Iron Ridge, near the village of Neda, about 6 miles south of Mayville. The character of these strata is shown in figure 1 and is described in the detailed section given below:

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[3] T. C. Chamberlin: Geology of Wisconsin, vol. ii, 1877, p. 336.

Section of Strata exposed in the Iron-ore Pit near Neda

	Feet
Mayville limestone.	
5. Dolomite, gray, crystalline, vesicular, in layers 1 to 2 feet thick...	12
4. Dolomite, yellowish gray, hard, crystalline, in irregular layers....	24
A break in sedimentation.	
Iron-ore bed.	
3. Iron ore, nearly black, impure..................................	1
2. Iron ore, oolitic, brown to red, in regular layers, with small pebble-like masses of iron at certain zones in the lower part......	12 to 30
A break in sedimentation.	
Maquoketa shale.	
1. Shale, bluish gray, calcareous..................................	8

The lower part of the Mayville limestone at this place, as elsewhere in Wisconsin, furnished several fossils which were mostly casts and molds of Zaphrentoid and Favositoid corals, the preservation of which was so poor as to make specific identification too uncertain for purposes of correlation. The species that could be satisfactorily identified have a wide vertical range and are not markers of any definite horizon in the early Silurian.

A succession of strata similar to those present in Iron Ridge are well exposed at Cascade Falls, 5 miles east of De Pere and about 10 miles south of Green Bay. The iron-ore bed at Cascade Falls furnished a number of fossils characteristic of the Maquoketa shale, including fragments which resemble parts of the rays of Stenaster sp., *Eurydictya montifera ? Lingula* cf. *cobourgensis, Strophomena wisconsinensis, Dalmanella tersa, Byssonychia intermedia, B.* cf. *radiata, Pterinea* cf. *demissa,* and *Liospira* sp. These species indicate the late Ordovician (Richmond) age of the iron formation.

The Virgiana zone is well exposed in the east quarry at Marblehead, about 20 miles north of Mayville, where the following section was made:

Section of Strata exposed in the Quarry at Marblehead

	Feet
Mayville limestone.	
6. Dolomite, yellowish gray, coarse-grained, in thick layers, containing numerous casts and molds of large shells of *Virgiana barrandei* var.	12
5. Talus-covered interval..	40
4. Dolomite, gray, crystalline, in thick, irregular layers.............	21
3. Dolomite, gray, fine-grained, in layers 4 to 5 inches thick.........	42
2. Dolomite, penetrated in a drilling but not exposed...............	58
Maquoketa shale.	
1. Shale, bluish gray..	1

The Mayville limestone is again well shown in an old quarry one-half mile south of the town of Peebles, near the south end of Lake Winnebago. Figure 2 shows the character of the strata at this place, a detailed section of which is given below:

Section of Strata exposed one-half Mile south of Peebles

Mayville limestone.	Feet
4. Dolomite, yellowish gray, hard, coarsely crystalline, with many cavities and numerous nodules of chert	6 to 9
3. Dolomite, brown to pink, hard, vesicular, in somewhat irregular layers 1 to 6 feet thick	30
2. Dolomite, dark gray, in thin irregular layers, separated by bands of chert	3
1. Dolomite, dark gray, with a few chert nodules	20

The base of this quarry is only a few feet above the top of the Maquoketa shale, as is shown by the numerous springs that issue in this region at a slightly lower level. In a ravine a few rods north of the quarry the contact of the Mayville limestone and the Maquoketa shale is clearly exposed, with no intervening bed of iron ore.

From the residual material found in the cavities of the limestone comprising the upper member (number 4) of the quarry section near Peebles the following fossils were among those collected:

Favosites sp.
Halysites catenulatus
Lyellia cf. *thebesensis*
Dalmanella edgewoodensis
Orthis flabellites
Platystrophia daytonensis
Clorinda sp.
Rhynchonella ? janea
Rhynchotreta parva
Atrypa putilla

The above species of fossils indicate the Edgewood age of this limestone and leave little doubt that at least the lower 60 or 80 feet of the Mayville beds, and probably all of this limestone below the zone of *Virgiana barrandei* var. *mayvillensis*, belong to a time interval equivalent to the Edgewood formation of the Alexandrian series.

In the vicinity of Brillion, about 25 miles north of Peebles, the Virgiana zone of the Mayville limestone is well exposed 130 feet above the top of the Maquoketa shale, and it outcrops again 50 miles still farther north, at the township line about 6 miles west of Sturgeon Bay.

Correlation of the Mayville Beds of Wisconsin with the Alexandrian Rocks of northeast Illinois

The fossils listed above, that were collected from the upper layers of the limestone exposed in the quarry near Peebles, Wisconsin, clearly

correlate the lower and middle portions of the Mayville beds and their equivalents in Wisconsin with the Edgewood formation of Illinois and Missouri. The upper portion of the Mayville beds in Wisconsin, containing numerous shells of *Virgiana barrandei* var., can not be so definitely correlated with any horizon of Alexandrian rocks in northeastern Illinois. The stratigraphic position of the zone of *Virgiana barrandei* var. in the upper Mayville beds, overlying the Edgewood portion of the Mayville in apparent conformity, is similar to that of the *Platymerella manniensis* horizon in northeast Illinois, which there immediately succeeds the Edgewood limestone without any distinct sedimentary hiatus. However, in some places, but not everywhere, in southwestern Illinois and eastern Missouri the *Platymerella manniensis* zone is separated from the underlying Edgewood limestone by an erosional unconformity.

The genera Virgiana and Platymerella are very closely related. The genus Virgiana was defined by Twenhofel in 1914 to include the species described by Billings as *Pentamerus barrandei,* later referred by Schuchert to the genus Clorinda, and two of its varieties, all of which were known only from the Anticosti region. Of this genus Twenhofel says:[4]

"In the Becsie River formation of the Anticosti section occurs the shell described by Billings as *Pentamerus barrandei,* which in its young stages has all the characters of a true Clorinda. With maturity, however, the shell attains large size, becomes decidedly elongate, narrow, and pronouncedly galeatiform and the fold and sinus become reversed, the latter being obliterated and transformed into a fold by the development of an axial rib, and the former disappearing through bifurcation of the initial fold producing a sinus at the margin. The interior is that of Clorinda."

Some of the shells of Platymerella, defined by Foerste in 1909, show no distinct mesial fold or sinus on either valve, but many of them have a sinus in the dorsal valve and a fold on the ventral, the latter having been formed by the repeated division of a single plication which occupied the bottom of what was originally a sinus, as shown in plate 16, figures 11 and 12. The sinus in the dorsal valve of Platymerella was likewise developed by the repeated division of a medial plication or fold. However, the ventral valve of Platymerella is never so galeate, nor is the mesial fold so keeled, as in the shells of Virgiana. It seems probable that the Upper Mayville beds in Wisconsin belong to a different geological province from that in which the limestone in Illinois containing *Platymerella manniensis* was laid down, and the direct correlation of these horizons is not yet certainly established.

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[4] W. H. Twenhofel: The Anticosti Island faunas. Canada Geol. Survey, Mus. Bull. no. 3, Geol. series no. 19, Oct., 1914, p. 27.

No older Silurian strata corresponding to the Girardeau limestone of southwest Illinois and eastern Missouri are known in Wisconsin.

Correlation of the Alexandrian Rocks of the Mississippi Valley with the early Silurian Strata of the Anticosti Embayment

There are two fossil zones in the Alexandrian series of the Mississippi Valley whose equivalents can be recognized in the section of strata exposed on Anticosti Island, recently described by Twenhofel.[5] One of these is the Stricklandinia horizon, which, in Illinois, occurs 18 to 25 feet above the base of the Sexton Creek formation, and contains shells of a number of species of Stricklandinia, among which *S. pyriformis, S. pyriformis* var. *elongata, S. breviuscula,* and *S. circularis* respectively resemble Billings species, *S. davidsoni, S. salteri, S. brevis,* and *S. lirata,* which occur in the upper part of the Gun River[6] formation of Anticosti Island as defined by Schuchert and Twenhofel.

Associated with the species of Stricklandinia in the limestone of Sexton Creek age in northern Illinois are *Diphyphyllum cæspitosum. Schuchertella pecten* var. *Plectambonites transversalis, Orthis flabellites, Platystrophia daytonensis, Pentamerus oblongus,* and *Triplecia* aff. *insularis* var. *anticostiensis.* These species are also found in association with the shells of Stricklandinia in the upper part of the Gun River formation of the Anticosti region. From the resemblance of the species of Stricklandinia in variety and in the number of individuals, and from the similarity of their associates, in the middle part of the limestone of Sexton Creek age of northern Illinois, to those in the upper part of the Gun River formation of Anticosti Island, it seems certain that the Stricklandinia zone in these widely separated regions represents about the same period of time, and that there was a sea connection between the Mississippi Valley basin and the Anticosti embayment during the time the rocks of this zone in the two areas were laid down.

Another horizon in the Alexandrian rocks of Wisconsin that can be confidently correlated with a definite portion of the Anticosti section is the Virgiana zone. In Wisconsin shells of *Virgiana barrandei* var. are found only in the upper part of the Mayville beds. In the Anticosti Island section *Virgiana barrandei* is a guide to the upper part of the Becsie River[7] formation, where the shells of this species are numerous and exhibit a multiplicity of variation, as they do in Wisconsin.

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[5] W. H. Twenhofel: The Anticosti Island faunas. Canada Geol. Survey, Mus. Bull. no. 3, Geol. series no. 19, Oct., 1914.

[6] Charles Schuchert and W. H. Twenhofel: Ordovicic-Siluric section of the Mingan and Anticosti islands, Gulf of St. Lawrence. Bull. Geol. Soc. Am., vol. 21, no. 4, 1910, pp. 708-713.

[7] Schuchert and Twenhofel: Bull, Geol, Soc. Am., vol. 21, 1910, pp. 705-708.

Parastrophia lenticularis and *Cœlospira planoconvexa* are associated with *Virgiana barrandei* in the Anticosti Island region. A form very close to *P. lenticularis* is also common in the Virgiana zone in Wisconsin, and *Cœlospira planoconvexa* was reported by Whitfield from a corresponding horizon of the Mayville beds near Hartford, Wisconsin. There seems no doubt that the Virgiana zone in the upper part of the Mayville beds in Wisconsin is to be correlated with the zone of *Virgiana barrandei* in the upper part of the Becsie River formation of Anticosti.

The lower and middle parts of the Mayville beds, which correspond in time to the Edgewood formation of Illinois and Missouri, occur below the Virgiana zone in Wisconsin, and are thus shown to be older than the corresponding strata containing *Virgiana barrandei* in the Anticosti region; but they can not be readily correlated with any definite horizon in the Anticosti section. However, from the relation of the strata bearing Edgewood fossils to the Virgiana zone in Wisconsin, the Edgewood formation can not be younger than about the middle of the Becsie River division of the Anticosti Island section.

The Girardeau limestone, which is the oldest of the Alexandrian formations in Illinois and Missouri, is not represented in Wisconsin or northeastern Illinois. Its horizon can not be definitely recognized in the Anticosti section, but it probably corresponds in time to the lower part of the Becsie River formation.

Relation of the Sexton Creek Limestone to the Cataract Formation

In view of the fact that *Cœlospira planoconvexa* is associated with *Virgiana barrandei* in the Anticosti region and has been found associated with the variety of this species in the Upper Mayville beds at Hartford, Wisconsin, and that it is a characteristic fossil of the basal (Manitoulin) member of the Cataract[8] formation, it is possible that the Virgiana horizon (Upper Mayville beds) of Wisconsin is to be correlated with the basal part of the Manitoulin member of the Cataract formation in Ontario, but it more probably belongs to a time shortly preceding the Cataract. The Manitoulin member not only contains *Cœlospira planoconvexa* in considerable abundance, but also *Rhinopora verrucosa* and a number of other species characteristic of horizons near the middle of the Sexton Creek limestone, with which formation the Manitoulin member of the Cataract is probably equivalent in time. It is noteworthy that no shells of Virgiana or of the numerous species of Stricklandinia that are

[8] Charles Schuchert: Medina and Cataract formations of the Siluric of New York and Ontario. Bull. Geol. Soc. Am., vol. 25, no. 3, 1914, pp. 277-320.

common in the limestone of Sexton Creek age in northern Illinois have been found in the Cataract formation. The fauna of the limestone of Sexton Creek age in Illinois is more closely related to that of the Gun River formation in the Anticosti region than to that of the Cataract and seems to indicate during this time a more direct sea connection of the upper Mississippi Valley basin with the Anticosti embayment than with that portion of the epicontinental sea in which the rocks of the Cataract formation were laid down.

History of the Alexandrian Epoch in the Mississippi Valley

The earliest deposits of the Alexandrian series in the Mississippi Valley comprise the Girardeau limestone which accumulated in an arm of the sea that advanced from the Gulf of Mexico region, reaching a few miles north of Cape Girardeau, Missouri. Deposition of this limestone was closed by the more or less complete withdrawal of the sea, and the sediments of the succeeding Edgewood formation were laid down during the next advance of this southern sea, which extended north as far as Will and Kendall counties, Illinois. That portion of the Mayville beds in Wisconsin that corresponds in age to the Edgewood limestone in Illinois is thought to have been deposited in a basin that had a northern sea connection and was separated from the Illinois basin by a land area or other barrier across southern Wisconsin or northern Illinois. This assumption seems justified on account of the difference in the fossils associated with the characteristic Edgewood species in Wisconsin compared with those in Illinois. The presence of the Virgiana zone near the top of the Mayville limestone appears also to indicate a connection of this province with the Anticosti region during the time the Upper Mayville beds were deposited. If this assumption is correct, these strata of Edgewood age in Wisconsin belong to a different province from that in which the Edgewood strata in Illinois and Missouri were laid down, and should very appropriately continue to bear the name "Mayville limestone."

In northeastern Illinois the zone of *Platymerella manniensis* immediately follows the Edgewood limestone without clear evidence of a sedimentary break, although in places in Calhoun County, in southwest Illinois, and in Pike County, Missouri, a distinct unconformity separates these horizons. *Platymerella manniensis* occurs also in rocks belonging to a corresponding horizon in western Tennessee, and this species is thought to have entered the Mississippi Valley from the Gulf of Mexico region, as did the earlier Edgewood fauna. The geological provinces of Edgewood time in this part of the Mississippi Valley appear to have re-

mained practically unchanged until after the limestone of the *Platymerella manniensis* zone was deposited, after which there occurred movements of sufficient importance to materially change the outlines of these basins. If this interpretation is correct, the most important movements of this time in the Mississippi Valley occurred immediately after the deposition of the limestone of the *Platymerella manniensis* zone, instead of just before. For this reason, it is here proposed to shift the upper boundary of the Edgewood formation and the basal part of the Sexton Creek limestone 3 or 4 feet higher than formerly, placing it at the top of the limestone containing *Platymerella manniensis* in Illinois and Missouri, instead of at the base of this zone, where it has previously been drawn.

Deposition of the limestone containing *Platymerella manniensis* was followed by crustal movements, which changed in a very important way the outlines of the basins in which the Edgewood strata were accumulated. Disturbances in the Ozarkian region resulted in the formation of an arch trending toward the northeast nearly through the present site of Saint Louis. This arch formed a barrier to the advance of the southern sea, not only during all of Sexton Creek time, but it remained effective during the subsequent times of submergence of this region throughout the remaining part of the Silurian and all of the Lower and Middle portions of the Devonian period. The Sexton Creek sediments that accumulated in the basin south of this barrier are well exposed in Alexander and Union counties, in southwestern Illinois, where they have an aggregate thickness of about 70 feet.

Nearly or quite coincident with the Ozarkian movement there occurred warping in the northern Illinois-southern Wisconsin area, which submerged the barrier that existed there in Edgewood time and permitted the sea from the Gulf of Saint Lawrence region to extend toward the west and south as far as Calhoun County, in western Illinois. In this northern basin the Stricklandinias flourished in great numbers and variety near the middle of Sexton Creek time. During the same time in the southern basin in Illinois and in the Brassfield basin of Ohio and Kentucky the only known species of that genus was *Stricklandinia triplesiana,* which also occurs associated with typical forms of *Triplecia ortoni* in the middle part of the Sexton Creek limestone along Sexton Creek, in southern Illinois, from which creek the name of the formation was taken. To the rocks in this southern basin that are equivalent in age to the Brassfield strata of Ohio and Kentucky it is proposed to restrict the name Sexton Creek limestone. The strata of corresponding age that accumulated in the northern basin, including western Illinois and eastern Mis-

souri north of Saint Louis and northeastern Illinois, are well developed and clearly exposed along Kankakee River about 5 miles south of Richey, and hence these will hereafter be referred to by the name "Kankakee limestone." From the similarity and abundance of the species of Stricklandinia and other fossils in this horizon compared with those in the upper part of the Gun River formation of the Anticosti region, it is thought that this embayment in northeastern Illinois was connected toward the northeast with the Anticosti Island region in the Gulf of Saint Lawrence during Sexton Creek time.

Description of Species [9]

GENUS SCHUCHERTELLA GIRTY

Schuchertella pecten var. *robusta* n. var.

Plate 16, Figure 1

Description: Shell semielliptical in outline; width about 1½ times the length; greatest width at the hinge line; cardinal extremities forming nearly right angles with the sides. A nearly complete shell measures 1¹/₁₆ inches long, 1½ inches wide, and has a convexity of about ¼ inch.

Ventral valve moderately concave in general contour, but flattened toward the cardinal extremities, the greatest concavity near the middle, without mesial sinus; beak moderately large, somewhat distorted; cardinal area of moderate height, extending to the extremities of the hinge line.

Dorsal valve with convexity about equalling the concavity of the ventral valve, highest near the middle, from which the surface curves rather steeply to the cardinal margin and more gently to the front and lateral margins; flattened toward the cardinal extremities; no mesial fold or sinus; beak inconspicuous.

Surface of both valves marked by rather fine, narrowly rounded, or subangular radiating striæ of unequal size, which divide two or three times between the beak and the margins, and by numerous very fine concentric lines, and a few much stronger lines of growth.

Remarks: This variety differs from the very variable species *S. pecten* of the Anticosti region in the larger size and coarser expression, the greater convexity of the ventral valve, and the greater irregularity in the size of the radiating striæ.

Horizon and locality: Kankakee limestone, near Oswego, Illinois.

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[9] The writer wishes to acknowledge his indebtedness to Prof. Charles Schuchert and Dr. W. H. Twenhofel, through whose kindness a comparison of the species of fossils discussed and described in this paper was made with allied species of the Anticosti region.

GENUS CLORINDA BARRANDE

Clorinda transversa n. sp.

Plate 16, Figures 2 and 3

Description: Shell transversely subelliptical in outline; a little wider than long; hinge line shorter than the greatest width, which is near the middle of the shell; front margin slightly extended. Specimens of nearly average size have a length of $3/8$ to $3/4$ inch, a width of $3/4$ to $7/8$ inch, and a thickness of $3/8$ to $5/8$ inch.

Ventral valve arched from beak to front; depressed along the median portion in a rather broad mesial sinus, which extends from the beak to the front margin; on each side of the sinus the curvature is rather abrupt to the lateral and cardinal margins; the beak is pointed, elevated, and strongly incurved; the cardinal area rather high, concave; spondylium rather deep, supported by a high, slender median septum.

Dorsal valve much less arcuate than the ventral, its greatest convexity in the umbonal region; the surface moderately convex from beak to front and elevated into a prominent mesial fold, which becomes rather broad in the anterior portion of the shell, where it is bounded by a poorly defined depression; antero-lateral portions nearly flat, postero-lateral slopes rather gentle; beak pointed and strongly incurved beneath that of the opposite valve.

Surface of both valves nearly smooth, marked only by a few concentric lines of growth, which are more numerous toward the outer margin of the valves.

Horizon and locality: Associated with Triplecia aff. insularis in a zone about 18 feet above the base of the Kankakee limestone at Grafton, Illinois.

GENUS STRICKLANDINIA BILLINGS

Stricklandinia pyriformis n. sp.

Plate 16, Figures 8 and 9

Description: The shell is subovate to pyriform in outline; the greatest width below the middle; the anterior margin somewhat extended; rounded or sometimes with a slight emargination on each side of the middle. The valves are subequally convex; hinge line straight, from $1/3$ to $1/2$ the greatest width; the cardino-lateral angle about 90°.

Ventral valve rather regularly convex along the median line from beak to front, the greatest convexity a little posterior to the middle; without a distinct fold or sinus; the curvature rather gentle toward the antero-lateral margins, but steep in the postero-lateral regions, where the valve

becomes flattened in the more narrowed portion of the shell; the cardinal area is narrow, concealed when the valves are in place; beak very low and inconspicuous, incurved.

The dorsal valve nearly as convex as the ventral, gently curving longitudinally from beak to front; highest along the median line, but without a distinct fold; transversely, it is rather strongly convex, the curvature more abrupt toward the postero-lateral margins; sometimes with a slight depression near the front on each side of the median portion; beak small and incurved beneath that of the ventral valve.

Surface of both valves marked by numerous lines of growth, some of which are stronger than others, but without definite radiating markings. The dimensions differ greatly in different specimens. Those of about an average shell are: length, 2⅜ inches; greatest width, 1¾ inches; thickness, 1 inch.

Remarks: This form somewhat resembles *S. davidsoni* Billings in its generally large size, elongate form, and the short hinge line in proportion to the greatest width of the shell. It differs from Billings' species in being larger and thicker, in having a much shorter hinge line, in the widest part of the shell being at or anterior to the middle, and in the flattened postero-lateral margins. In some respects it also resembles *S. deformis* Meek and Worthen, from which it differs in the relatively shorter hinge line, the more symmetrical growth, the shell showing no strong concentric constrictions, and in the less oblong outline, the posterior half of the shell being relatively much narrower than in *S. deformis*.

Horizon: About 18 to 25 feet above the base of the Kankakee limestone at Hamburg, along Kankakee River 5 miles south of Richey, and at Elgin, Illinois.

Stricklandinia pyriformis var. *elongata* n. var.

Plate 16, Figure 7

Description: The shells of this variety differ from those of *S. pyriformis* chiefly in being much thinner, in having the hinge line nearly or quite as long as the greatest width of the shell, and the cardinal extremities more or less produced, so as to make the cardino-lateral angles slightly less than right angles. The shells are somewhat oblong in outline, a little longer than wide, about equally and very moderately convex, with greatest elevation along the median line, but without definite fold or sinus on either valve; the sides are nearly parallel, and the front margin regularly rounded; cardinal areas linear and beaks obscure.

The dimensions of a cast are: length, 1¼ inches; width, 1⅛ inches; thickness, about ½ inch.

Remarks: This variety differs from *S. salteri* in the more elongate form, the length being much greater in proportion to the width. From *S. triplesiana* of the Brassfield limestone it differs in the relatively greater length of the shell and in the absence of a mesial fold or sinus.

Horizon: Stricklandinia zone 18 to 25 feet above the base of the Kankakee limestone, at Hamburg, along Kankakee River above Custer Park, and at Elgin, Illinois.

Stricklandinia pyriformis var. *vasculosa* n. var.

Plate 16, Figure 6

Description: Shells having the appearance of young forms of *S. pyriformis*, but the surface of the casts marked by somewhat irregular ridges of unequal size, three to five of which extend longitudinally along the median portion. From the margins of this median area less prominent ridges curve downward and outward over the lateral portions of the shells, some of which divide once or twice before reaching the margin. The markings on the surface of the casts indicate the presence on the interior of the shells of a few longitudinal furrows in the median portion, from the borders of which low, rather broad, often bifurcating furrows extend downward and outward to the margins.

The shell is ovate in outline; the hinge line shorter than the greatest width; the valves subequally convex, without fold or sinus; the spondylium is moderately deep, and is supported by a short medium septum; the impressions of the crural processes are rather deep, slender, and somewhat diverging.

Horizon and locality: In the Stricklandinia zone 18 to 25 feet above the base of the Kankakee limestone, along Kankakee River near Custer Park, and at Elgin, Illinois.

Stricklandinia circularis n. sp.

Plate 16, Figure 4

Description: Shell subcircular in outline; length and width about equal, the greatest width near the middle; valves about equally convex; hinge line slightly longer than half the greatest width; cardino-lateral portions and the front and lateral margins rather regularly rounded.

Ventral valve gently convex, the greatest convexity near the middle; medial portion depressed longitudinally from beak to front, forming a shallow sinus, which becomes quite broad in the anterior half of the valve. The surface is gently convex transversely over the anterior and lateral

regions and curves more strongly to the hinge line on the posterior portion; no cardinal area; beak small, not much elevated, incurved.

Dorsal valve about equal in convexity to the ventral, somewhat elevated from beak to front along the median line, forming a low, poorly defined mesial fold, away from which the surface curves gently toward the front and sides and more strongly toward the cardinal margin; beak small and inconspicuous, incurved beneath that of ventral valve.

Surface of both valves marked by numerous indistinct, very fine lines of growth; without distinct radiating markings, but the fibrous structure of the shell, where partly exfoliated, sometimes gives the appearance of very fine radiating striæ.

Remarks: This species differs from *S. davidsoni* in its much shorter length and proportionally greater width and the absence of such a prominent anterior extension; from *S. lirata,* which it resembles in general outline, it differs in the absence of distinct radiating markings.

Horizon: Kankakee limestone at Oswego, Illinois.

Stricklandinia breviuscula n. sp.

Plate 16, Figure 5

Description: Shell subcircular in outline, a little wider than long, the greatest width slightly posterior to the middle; the lateral and anterior margins rounded; the valves nearly equal in size and convexity; hinge line straight, equalling about half the greatest width of the shell. The dimensions are: length, ¾ inch; greatest width, ⅞ inch; thickness, nearly ½ inch.

Ventral valve moderately convex, the greatest convexity at or posterior to the middle, the median portion depressed longitudinally into a rather broad shallow sinus. Cardinal area very narrow; beak low; spondylium rather short and supporting median septum very short.

Dorsal valve similar in form and convexity to the ventral, the median portion elevated from beak to front into an indistinct mesial fold; the surface is very gently convex or nearly flat on each side of the mesial fold in the anterior portion, with a stronger curvature over the cardinal and postero-lateral margins; beak small and somewhat incurved.

Surface with a few lines of growth near the margins, but without radiating markings.

Remarks: This species differs from *S. brevis* in its smaller size and in the stronger longitudinal convexity of the dorsal valve. It may prove to be a young form of *S. circularis,* which it resembles in general outline, but it differs from the normal shells of that species in the much smaller

size, the more prominent beak, and in the greater length in proportion to the width.

Horizon: Zone of Stricklandinia 18 to 25 feet above the base of the Kankakee limestone, at Elgin, and near Channahon, Illinois.

GENUS VIRGIANA TWENHOFEL

Virgiana barrandei var. *mayvillensis* n. var.

Plate 17, Figures 3 to 7

Description: Shell presenting a very considerable range of variation in size and appearance; unequally biconvex; subovate in outline; length about 1½ times the width, the greatest width anterior to the middle; anterior margin rounded. All the specimens are in the form of casts of the interior.

Ventral valve strongly arcuate from beak to front, the curvature increasingly convex toward the beak, the greatest convexity posterior to the middle, the median portion elevated into a more or less distinct fold. In the casts a sinus appears at the beak which soon becomes occupied by a plication that divides two or three times so as to form a mesial fold in the middle and anterior portions, which in some specimens is very prominent. The surface is strongly convex transversely in the anterior portion, becoming progressively more arcuate in the middle and posterior portions to near the cardino-lateral margins, above which it is abruptly curved toward the delthyrium; cardinal area arcuate; delthyrium large and triangular; beak high, arcuate, strongly incurved over the hinge line; spondylium deep, supported by a short median septum.

Dorsal valve gently convex from beak to front along the median line, highest in the umbonal region, where it is strongly convex transversely, the curvature becoming more gentle toward the anterior portion, where the valve is nearly flat; the median portion of old shells usually depressed so as to form an indistinct mesial sinus, which extends from near the beak to the front margin. No trace of a mesial sinus is present in the dorsal valves of young specimens, but instead they frequently bear an indistinct mesial fold; beak rather prominent and incurved beneath that of the ventral valve; crural impressions long, slender, and nearly parallel.

Surface of both valves marked by rather strong radiating striæ, which divide two or three times between the beaks and the margins, and by concentric lines of growth, which are more numerous near the margins.

There is great variation in the size of the shells, but the type specimen, which is near the average, measured as follows: length, 2¼ inches; greatest width, 1⅞ inches; thickness, 1¼ inches.

Remarks: This variety differs from *V. barrandei* in the broader convexity of the ventral valve from side to side, in the less sharp and prominent mesial fold, in the less distinct sinus in the dorsal valve, in the better defined radiating plications, and the larger size.

Horizon and localities: Upper part of the Mayville limestone; near Mayville, Brillion, and west of Sturgeon Bay, Wisconsin.

Virgiana barrandei var. *major* n. var.

Plate 17, Figures 1 and 2

Description: Shell broadly ovate in outline, with the greatest width in the anterior portion; the front margin rounded.

Ventral valve arcuate from beak to front, highest posterior to the middle, the curvature becoming progressively more convex posteriorly; transverse convexity very strong; the postero-lateral margins abruptly incurved, anterior margin less strongly convex; mesial fold in the casts extending from near the beak to the front, very high and prominent, especially in the middle and anterior portions; the beak is strongly elevated and incurved; spondylium large, supported by a strong median septum.

Dorsal valve much less convex than the ventral; highest posterior to the middle, where the longitudinal and transverse convexity is moderately strong; the curvature is gentle over the anterior portion, where the valve is frequently flat or concave; mesial sinus present only in the anterior portion, where it is broad, shallow, and poorly defined; beak moderately prominent; crural processes making strong impressions in the casts. Surface of both valves marked by numerous striæ, which divide two or three times between the beaks and the margins. The dimensions of a large specimen are: length, 2¾ inches; width, 2¼ inches, and thickness, 1¾ inches.

Remarks: Compared with *V. barrandei* var. *mayvillensis,* this form is much larger and broader, with much stronger mesial fold in the ventral valve and less distinct sinus on the dorsal, and weaker and more numerous radiating striæ.

Horizon and locality: Upper part of the Mayville limestone; at Marblehead, Wisconsin.

GENUS EURYPTERUS DE KAY

Eurypterus pumilus n. sp.

Plate 17, Figure 8

The ventral portion only is exposed in the type specimen of the above species. The shell is so thin and the test has been so flattened by pressure

FIGURE 1.—VIEW OF THE MAYVILLE LIMESTONE

The limestone overlies the iron ore in Iron Ridge, near Neda, Wisconsin

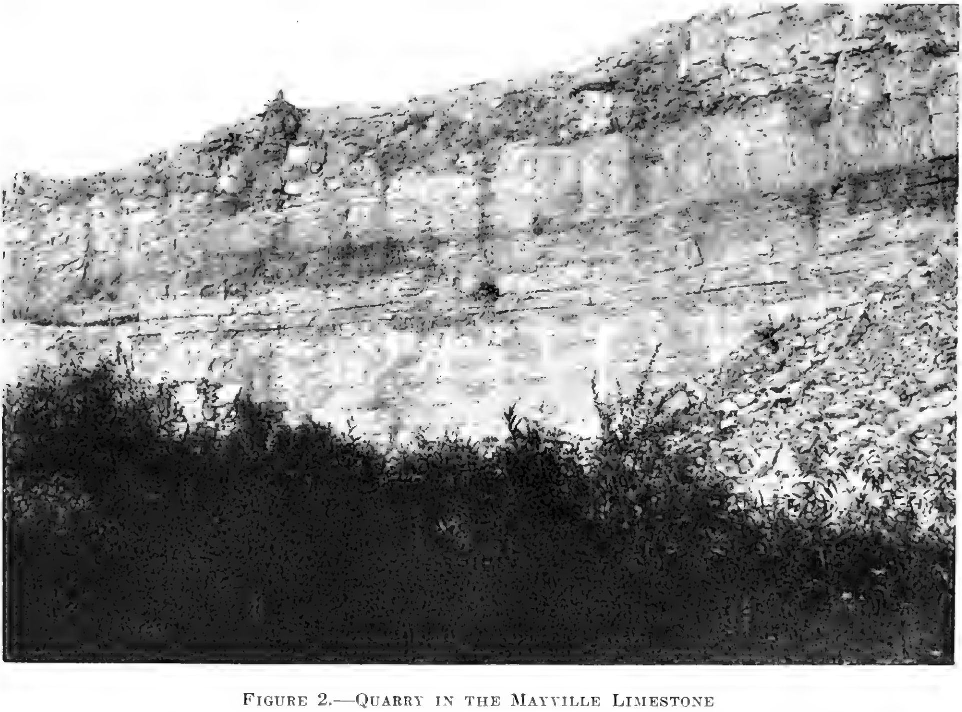


FIGURE 2.—QUARRY IN THE MAYVILLE LIMESTONE

The quarry is half a mile south of Peebles, Wisconsin. The upper layers furnish fossils characteristic of the Edgewood formation

MAYVILLE LIMESTONE

that the outline of the compound eyes and a few other features of the dorsal surface are visible from the ventral side.

Description: Body small; ovate-lanceolate in outline; entire length, 2 inches; greatest width about one-third of the distance from the anterior end, where it measured $^9/_{16}$ of an inch.

Carapace a little more than one-fifth of the total length of the body; subrectangular in outline; length, ½ inch; width, $^7/_{16}$ inch; lateral margins nearly straight, anterior margin gently convex-forward; antero-lateral angles rounded; posterior margin nearly straight except at the genal angles, where it curves slightly forward. Compound eyes moderately large, nearly one-third the length of the carapace, situated in front of the middle, more than twice as far apart as distant from the lateral margins, reniform, prominent; ocelli not visible. Ventral surface of carapace much broken.

Preabdomen about one-sixth the length of the body, wider than long, greatest width about the fourth segment; the edges of the ventral plates project slightly beyond the dorsal, which are slightly produced backward into short spines. Postabdomen a little more than one-third the length of the body, the width decreasing more rapidly in the first and second postabdominal segments than in the more posterior ones; the length of the segments progressively increasing posteriorly; post-lateral angles slightly produced into short spines.

Telson about one-fourth the length of the body, rapidly contracting from the articulation into a slender spiniform process, which tapers to a mucronate point, and is carinate on the ventral side.

Appendages indistinct; imperfect impressions of portions of the proximal parts of three appendages are visible on each side of the carapace, but are too indistinct to permit of description.

Horizon and locality: In the lower part of the Essex (Edgewood) limestone; near Essex, in Kankakee County, Illinois.

Explanation of Plates

Plate 15.—*Mayville limestone*

Figure 1.—View of the Mayville limestone.

The limestone overlies the iron ore in Iron Ridge, near Neda, Wisconsin.

Figure 2.—Quarry in the Mayville limestone.

The quarry is half a mile south of Peebles, Wisconsin. The upper layers furnish fossils characteristic of the Edgewood formation.

PLATE 16.—*Fossils from the Alexandrian Rocks*

FIGURE 1.—*Schuchertella pecten* var. *robusta* n. var.
Ventral view of a nearly entire specimen. Kankakee limestone, Oswego, Illinois.

FIGURES 2 and 3.—*Clorinda transversa* n. sp.
Dorsal and ventral views of a nearly entire cast; the type specimen. Kankakee limestone, Grafton, Illinois.

FIGURE 4.—*Stricklandinia circularis* n. sp.
Dorsal view of a nearly complete specimen. Kankakee limestone, Oswego, Illinois.

FIGURE 5.—*Stricklandinia breviuscula* n. sp.
Dorsal view of an entire specimen. Kankakee limestone, near Channahon, Illinois.

FIGURE 6.—*Stricklandinia pyriformis* var. *varicosa* n. var.
Ventral view of a cast of the interior; type specimen. Kankakee limestone, Elgin, Illinois.

FIGURE 7.—*Stricklandinia pyriformis* var. *elongata* n. var.
Dorsal view of an internal cast. Kankakee limestone, Elgin, Illinois.

FIGURES 8 and 9.—*Stricklandinia pyriformis* n. sp.
Dorsal and ventral views of a nearly entire shell; the type specimen. Kankakee limestone, Hamburg, Illinois.

FIGURE 10.—*Stricklandinia pyriformis* n. sp.
View of ventral valve of a young shell. Kankakee limestone, along Kankakee River, 5 miles south of Richey, Illinois.

FIGURES 11 and 12.—*Platymerella manniensis* (Foerste).
Ventral and dorsal views of nearly complete specimens; after Foerste.

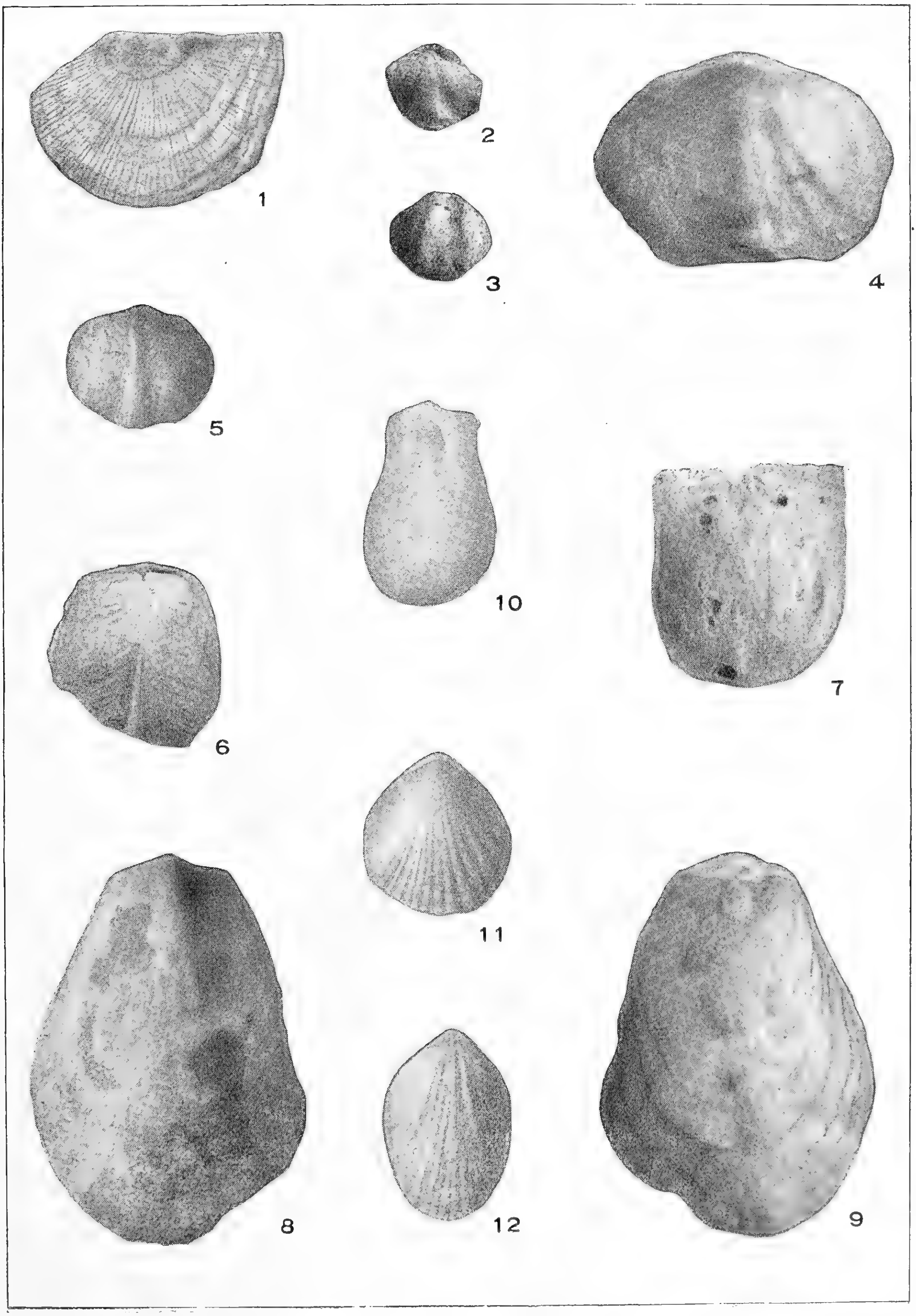
PLATE 17.—*Fossils from the Alexandrian Rocks*

FIGURES 1 and 2.—*Virgiana barrandei* var. *major* n. var.
Ventral and dorsal views of an internal cast of large size. Upper part of Mayville limestone, Marblehead, Wisconsin.

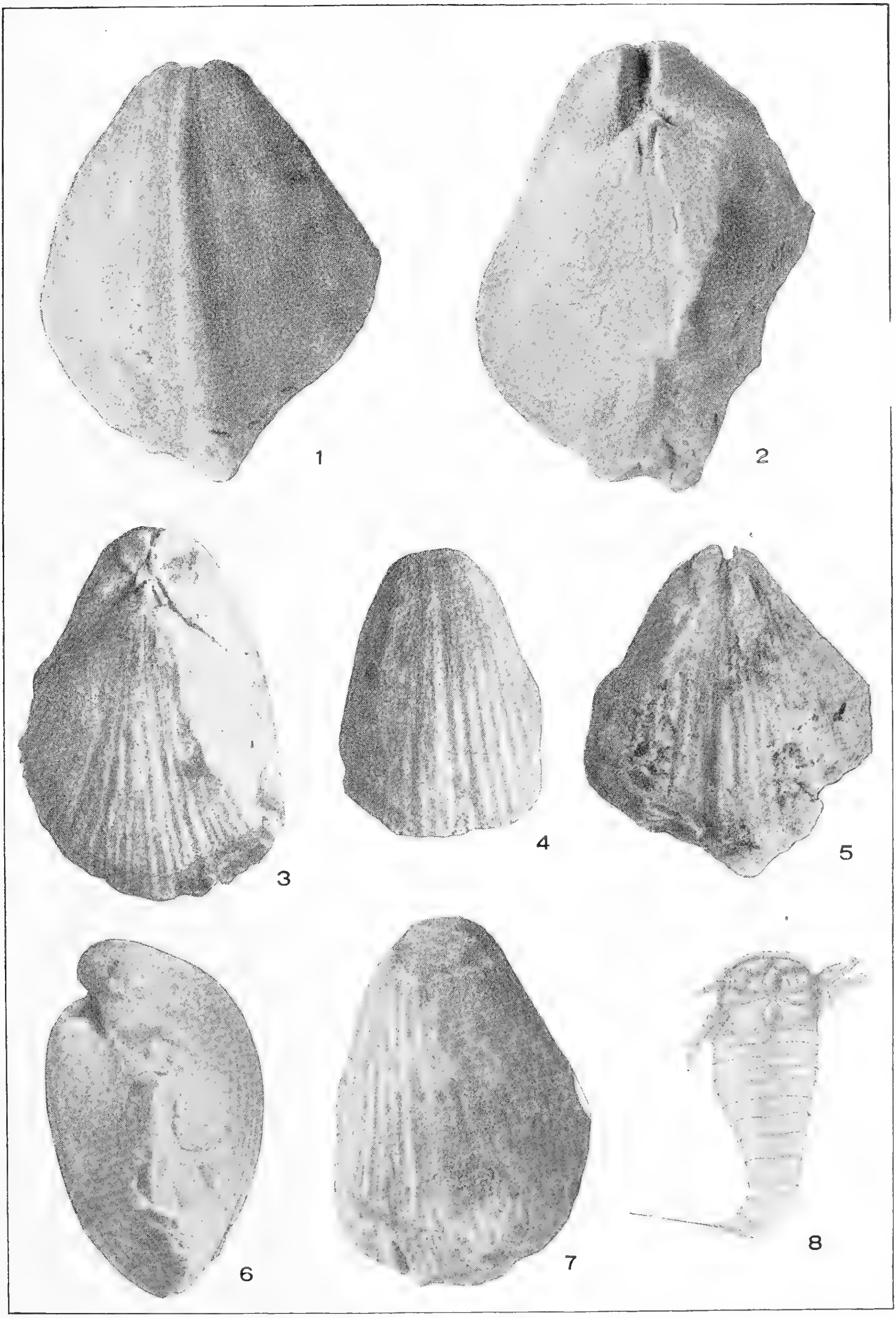
FIGURES 3, 6, and 7.—*Virgiana barrandei* var. *mayvillensis* n. var.
Dorsal, lateral, and ventral views of an internal cast; the type specimen. Upper part of Mayville limestone, near Mayville, Wisconsin.

FIGURES 4 and 5.—*Virgiana barrandei* var. *mayvillensis* n. var.
Ventral view of internal casts of two other shells. Upper part of Mayville limestone, near Mayville, Wisconsin.

FIGURE 8.—*Eurypterus pumilus* n. sp.
View of ventral surface of the type specimen. Natural size. Edgewood (Essex) limestone, near Essex, Illinois.



FOSSILS FROM THE ALEXANDRIAN ROCKS



FOSSILS FROM THE ALEXANDRIAN ROCKS

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PETROGRAPHY OF THE PACIFIC ISLANDS [1]

BY REGINALD A. DALY

(Presented before the Society December 28, 1915)

CONTENTS

PROPOSAL OF A COMPREHENSIVE EXPLORATION

Polynesia, Melanesia, and Micronesia, together with the isolated, open-ocean islands of the Pacific basin, include nearly 3,000 named islands. Not counting New Guinea, New Zealand, and their immediate satellites, the total area of these islands is about 73,000 square (statute) miles, or 189,000 square kilometers. Nearly one-half of the total is covered by a dozen islands, among which are Hawaii, Viti Levu, Vanua Levu, New Pomerania, New Mecklenburg, and New Caledonia. The other islands average only about 12 square miles in area. That part of the ocean basin in which the islands are situated measures 35,000,000 square miles (90,000,000 square kilometers). Hence the complete mapping and investigation of a total land area less than that of the State of Nebraska would bring in practically all the information that can ever be obtained concerning the bedrock geology of one-sixth of the earth's surface. It is highly desirable that a single association shall soon undertake a comprehensive study of these thalassic islands. If their geology, botany, zoology,

[1] Manuscript received by the Secretary of the Society January 2, 1916.

and anthropology were thus fully worked out, the results for general science would be incalculably beneficial.

This paper is intended to emphasize the rich field for research to be found in the petrography of the Pacific islands. It is possible to summarize in a few pages nearly all that has been done so far in this field. The facts are most readily assembled in tabular form, and the three following tables tell the story of published petrographic results up to January 1, 1916. The tables primarily refer to Oceanica, but some other islands are included. New Zealand, New Guinea, and their satellites, as well as the islands close to continents, are not included. The tables are doubtless not quite complete, but they serve to stimulate the active petrologist. In spite of the very small amount of systematic work yet accomplished, the published facts can not fail to suggest certain questions regarding the origin of the Pacific lavas and other island rocks. Some of the problems will be briefly considered, particularly those dealing with the volcanic islands.

"Continental" Rocks

Table I lists the thirty-three or more islands which are now known, or have been suspected, to contain quartzose rocks, basic schists, serpentine, or deformed limestones. These are all rocks that abound in each of the continents and, for convenience, they may be called "continental rocks." Ellis's statement that he found quartz-feldspar rock on Borabora of the Society Group and Commander Thomson's reported discovery of granite and slate on Easter Island are both doubtful and need testing in the field. With those exceptions, all the Oceanican continental rocks so far known to the writer in published record lie west of a straight line joining the eastern Fijis with the Mariana Group. In principle this distribution is, of course, well known and has long been explained in connection with the theory of Tertiary fragmentation of the Australia-Melanesia continent.

Volcanic Islands

The much longer Table II summarizes present-day knowledge of those open-ocean islands which are wholly or largely composed of volcanic rocks. To date 370 islands have been definitely so described. The whole number of them probably well exceeds 600. Of these only about 180 have furnished any information regarding the nature of their constituent rocks. Not a single island has yet been studied and mapped in the detail suited to the needs of petrology.

In Table II there are 82 names of rock species. Most of these are readily grouped into four classes, respectively representing basaltic, ande-

sitic, peridotitic, and "alkaline" magmas. Three other classes include transitions between basaltic rock and each of the other three chemical types or groups. An eighth class comprises quartz-bearing rocks, and a ninth includes a few species not certainly referable to any of the other classes.

So far as the records go, the relative importance of these classes is suggested by Table III, which shows the number of islands where each rock species has been reported.

Andesites and their genetic Associates

In spite of the obvious difficulties, due to faulty nomenclature and general lack of chemical analyses, it is clear that typical olivine-bearing plagioclase basalt and as typical pyroxene andesite have been most often discovered, and it is safe to hold that the two species mentioned are by long odds the commonest lavas in Oceanica. The two occur side by side in at least 17 of the islands listed. They are connected by transitional varieties, including many olivine-free basalts, gabbros, diabases, etcetera, as well as the species named in Class 2 of Table III. All these relations are very often repeated on the continents, where, moreover, pyroxene andesite and plagioclase basalt are associated, not only in eruptions of the Recent Period, but also in nearly all the great rock systems since at least the late Precambrian.

When a given kind of rock association persists, both in time and space, it is reasonable to suspect syngenesis for the species involved. Elsewhere the writer has elaborated the thesis that pyroxene andesite and certain ultra-basic rocks may be complementary differentiates from plagioclase basalt.[2] More recently Cross has concluded that the andesites and other igneous rocks of the Hawaiian Islands have been derived from a general basaltic magma by a process of pure differentiation.[3] The experiments of Bowen have fully shown the possibility that the differentiation is based on the gravitative separation of crystals, though the other possibility—that the splitting is due to the gravitative separation of non-consolute liquids chemically similar to the phenocrysts, can not be excluded.[4] In view of this uncertainty, the present writer prefers to use the expression "gravitative differentiation," rather than "fractional crystallization" or "liquation," to indicate the method of splitting.

In the writer's opinion, most of the rock species named in Classes 2, 3, 4, and 5 of Table III are best explained as formed by the more or less

[2] Jour. Geology, vol. 16, 1908, p. 401; Memoir 38, Geol. Survey Canada, 1912, p. 782; Igneous rocks and their origin, New York, 1914, p. 375.

[3] W. Cross: Professional Paper 88, U. S. Geol. Survey, 1915, p. 87.

[4] N. L. Bowen: Amer. Jour. Science, vol. 39, 1915, p. 175, and vol. 40, 1915, p. 184.

advanced gravitative differentiation of common olivine basalt, the most abundant of Pacific lavas. The grounds for this belief will not here be repeated. The chemistry and mineralogy of basalt, pyroxene andesite, dunite, wehrlite, lherzolite, and the corresponding transitional types suggest that the splitting has been, in a sense, spontaneous, and not induced by the incorporation of any foreign material except, perhaps, vadose water in a few cases. The natural condition for such splitting would be a comparatively low temperature for the basaltic magma. If, at such a temperature, a certain percentage of the phenocrystic material were to segregate and then settle out, the remaining liquid would have the composition of molten pyroxene andesite. The mother liquor might freeze in the volcanic vent, giving a dioritic rock, or freeze on the surface after its extrusion as a lava flow, giving the andesitic type.

The temperature appropriate for gravitative differentiation may be temporarily established in a basaltic vent at any epoch in its history, but probably most often toward the close of the life of a great basaltic volcano, when the feeding magmatic chamber approaches the temperature of final solidification. Even then, however, flows of primitive basalt may often be expected to alternate with flows of andesite, and these with flows of picrite or picritic basalt. Such alternations are common among the superficial, and therefore younger, lava flows of the gigantic Hawaiian volcanoes.[5] In general, the field relations of the Pacific island lavas seem to agree with the hypothesis of gravitative splitting for the andesites, etcetera; yet the hypothesis is emphasized more to indicate the need of special, detailed field-work in the islands and to serve as one of the guides in that research than to suggest any finality for the explanation.

Alkaline Rocks

The twenty-six species listed in Class 7 are called "alkaline," after the Rosenbusch tradition. The word is, of course, used metaphorically. Thus in Class 7 are placed several species which are not rich in alkalies, but the world over are regularly, and doubtless genetically, associated with alkali-rich species.

Alkaline rocks have been found in thirty-five of the islands, representing thirteen major archipelagos and two isolated islands. In thirty

[5] In Professional Paper 88 of the U. S. Geological Survey (p. 92), Cross states that the writer believes all of "the upper 6,000 feet of Mauna Kea" to be composed of andesitic and closely allied, trachydoleritic, rocks. This statement is based on a complete misapprehension. Throughout his published account of the lavas on the upper slopes of Mauna Kea (Journal of Geology, vol. 19, 1911, pp. 297, 311, 313), the writer refers only to the *surface* rocks on the *eastern* side of the volcano. It is entirely possible that typical olivine basalt occurs at the surface in "the upper 6,000 feet" of Mauna Kea and very probably is there much more abundant below the surface.

islands, including examples in twelve archipelagos, as well as two isolated islands, the alkaline rocks are associated with feldspar basalt or its chemical equivalent, gabbro. With abundant repetition the "Atlantic" and "Pacific" types of lava are both found in the same small island. Here, as elsewhere in the world, the hypothesis that the two suites are differentiation products of primordially distinct magmas meets obvious and apparently fatal difficulties. In the Auckland, Fiji, Hawaiian, Juan Fernandez, Samoan, and Society groups the immense preponderance of the subalkaline basaltic rocks is already clear.

In fact, the simplest explanation of nearly all the alkaline rocks of the Pacific is that they have been derived from primitive basaltic magma. Cross has recently adopted this view of the trachytic, nephelite-bearing, and melilite-bearing rocks of the Hawaiian Islands.[6] He states that the alkaline rocks in Hawaii and elsewhere are "products of the same general process of differentiation as the other rocks with which they are associated. They are simply the extreme phases of the group now known and are connected by intermediate lavas with rocks assumed by Daly to result from gravitative differentiation." Cross makes these statements without giving any proofs or any suggestion as to how or why a pyroxene andesite was differentiated from the primitive basalt in one place and a phonolite, a melilite basalt, or a soda trachyte in another.

However, it is right to suppose that the conditions must have been different in the two cases. What, then, is the controlling factor in the generation of an alkaline rock from basaltic magma? Smyth's thesis, that the alkali-rich rocks are the results of concentrating alkalies by magmatic emanations or "mineralizers," is very helpful. It should specially aid some petrologists to emerge from the mysticism induced by that overworked term "differentiation." Too many authors have considered their intellectual work done when they have concluded that a rock or a rock series is due to differentiation. Seldom do petrographic memoirs contain a word about the mechanism or steps of the magmatic splitting, which the authors of the memoirs affirm to be the origin of the rocks concerned. For the alkali-rich rocks Smyth has shown a more excellent way; yet his thesis seems to need an important supplement. His essay does not answer the question as to why the magmatic gases were specially abundant and hence specially able to segregate the alkalies of an initially subalkaline magma. It does not explain the very general association of lime-rich magmas with alkali-rich magmas. It does not explain the abundance of lime minerals *in* many alkali-rich rocks. It does not explain the generation of feldspathoids in place of the usual feldspars.

[6] W. Cross: Professional Paper 88, U. S. Geol. Survey, 1915, pp. 87 and 90.

These and allied facts have prompted the suggestion that the solution of sedimentary material in subalkaline magma has led to the development of many of the so-called alkaline rocks.[7] Limestone is here the most significant of the sediments, on account of its fluxing power, its inoculating power, and its extremely high content of volatile matter. Yet other kinds of sediment would in less degree affect the chemical equilibrium of a subalkaline magma in which they might be dissolved. According to the writer's hypothesis, the most potent "magmatic mineralizers" engaged in concentrating the alkalies while forming alkali-rich submagmas are largely "resurgent" rather than "juvenile" in origin. This recognition of syntexis and sedimentary control in the development of such rocks as soda trachyte, phonolite, foyaite, etcetera, seems to supply the lack noted in Smyth's hypothesis.

Cross and Marshall have rejected the writer's explanation of the alkaline rocks of Hawaii and Tahiti respectively. Each is doubtful that the volcanic vents supplying the alkaline magmas pass through limestone which could be assimilated in the required quantity.[8] But the percentage of limestone so dissolved in a large body of hot basalt may be very small, in order to cause the development of a flow of phonolite or a flow of the strongly contrasted melilite basalt. Can any one doubt the possibility that much calcareous material is included in the submarine portions of the Hawaiian and Tahitian volcanic masses? Is it extreme to hold that enough of this deep-lying sediment is present to match the relatively minute volumes of alkaline rocks in Hawaii and Tahiti? Clearly the origin of the alkaline rocks can not yet be demonstrated, but little progress toward that demonstration is made by implying or asserting that no limestone beds have been cut by volcanic vents in islands like Hawaii and Tahiti.

Other rather remarkable arguments have been published against the hypothesis of limestone control. One of them may be quoted: "If an alkaline rock cuts a limestone in dikes or stocks, this fact proves that that limestone did not have anything to do with the alkalic character of the cross-cutting body."[9] To a believer in magmatic stoping and abyssal assimilation this "proof" carries no conviction.

However, this is not the place to discuss the objections in detail; suffice it to say that those so far announced have not shaken the grounds on which the sedimentary-control hypothesis of the alkaline rocks has been founded.

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[7] R. A. Daly: Bull. Geol. Soc. Am., vol. 21, 1910, p. 87; Igneous rocks and their origin, New York, 1914, pp. 393-445. Cf. C. H. Smyth: American Journal of Science, vol. 36, 1913, p. 33.

[8] W. Cross: Professional Paper 88, U. S. Geol. Survey, 1915, p. 90; P. Marshall: Trans. New Zealand Institute, vol. 47, 1915, p. 372.

[9] W. Cross: Op. cit., p. 90.

Quartz-bearing igneous Rocks

As already noted, the quartz-bearing lavas, Class 8 of Table III, are probably confined to the region of continental fragmentation in the southwest Pacific. Their origin is a world problem specially affecting the geology of the continents, and the Pacific islands are not likely to shed much light on that complex subject. Yet in island or mainland one of the chief facts to be considered is the general association of feldspar basalt or its chemical equivalent with quartz-bearing lavas, where the latter types do occur. That fact is explained by the syntectic-differentiation theory of igneous rocks. No other explanation covering the ascertained field, chemical, and mineralogical relations has yet been published.

Miscellaneous Types

The species listed in Class 9 have uncertain affinities. Most of them are chemically related to basalt or ordinary gabbro, and their genesis probably involves no important principle not represented in the origin of Classes 2 to 7, inclusive.

Conclusions

The available petrographic data do not yet, of course, permit of final conclusions as to rock origins, but they do suggest: (1) that underneath the Pacific the only primary magma is, and long has been, of basaltic composition; (2) that the pyroxene andesites and picritic types are direct differentiates of this primary magma itself; (3) that the alkaline rocks may possibly be due to the solution of comparatively small proportions of limestone in the primary basalt, the syntexis being usually masked by differentiation.

The primary basalt may most simply be conceived as forming a continuous stratum beneath the whole ocean basin. From this subcrustal stratum material has been eruptible, locally and from time to time. The failure of quartz-bearing lavas in most of the basin suggests that the basaltic substratum is there not overlain by a solid quartzose crust, as it is in continental areas. With this conception may be correlated the geodetic proofs of specially high density beneath the Pacific Ocean.

Suggestion and hypothesis have great value if they lead to action, to renewed search in nature for the facts. A glance at the larger aspects of Pacific petrology shows how pitifully slight is our knowledge of the island petrography. Now is not the time for settled convictions. Now is the time for concerted, persistent effort, leading to a thorough exploration of the Pacific archipelagos, under the auspices of a single institution with a staff of cooperating observers.

TABLE I.—ISLANDS OF OCEANICA SHOWING OUTCROPS OF "CONTINENTAL" ROCKS

Islands	Rock Types	Authorities [10]
Auckland Group:		
Auckland	Granite, rhyolite	Speight and Finlayson.
Disappointment	Rhyolite	Speight and Finlayson.
Bismarck Group (including Admiralty Islands):		
Lou	Microgranite	Wichmann (56).
Macada	Granite, quartz diorite, syenite	Sapper (37).
New Hanover	Granite, quartz diorite	Sapper (37, 38).
New Mecklenburg	Granite, quartz diorite, gneiss	Sapper (37, 38).
New Pomerania	Dacite	Lehmann.
Bonin Group	Serpentine, deformed Eocene limestone, liparite	Yoshiwara.
Caroline Group:		
Map	Granite, syenite, serpentine, amphibolitic schist	Kaiser.
Vela (Truk)	Amphibolitic schist	Krämer.
Yap	Amphibolitic, actinolitic, and talcose schists	Krämer.
Chatham Group	Sericite schist, "older" (Cretaceous ?) limestone	Diesseldorff.
Fiji Group:		
Vanua Levu	Diorite, rhyolite, quartz porphyry, dacite	Guppy (12).
Viti Levu	Granite, quartz porphyry, quartz diorite, quartzite, sandstone, amphibolite, crystalline limestone, slate.	Wichmann (55), Marshall (28).
Kermadec Group	Granite fragments	Oliver.
New Caledonia	Mica, chlorite, talc, and hornblende schists, crystalline limestone, quartzite, serpentine, Mesozoic sediments.	Iddings, Marshall (28).
New Hebrides Group:		
Espiritu Santo	Deformed Miocene limestone	Mawson.
Malekula	Gneiss (?)	Marshall (28).
Pelew Group:		
Baobeltaob	Quartz sandstone	Wichmann (51).
Society Group:		
Borabora	Quartz-feldspar rock	Ellis in Marshall (28).

[10] References given after Table II. The numbers indicate specific papers or books. See Marshall's "Oceania" and Iddings's "Igneous Rocks" for additional bibliography.

Islands	Rock Types	Authorities
Solomon Group:		
Bougainville	Dacitic rhyolite	Sapper (39).
Faro (Fauro)	Quartz felsite, quartz andesite, quartz porphyry, diorite.	Guppy (11), Marshall (28).
Florida Islands	Quartz porphyry, quartz diorite, dacite, serpentine	Guppy (11).
Guadalcanar	Basic schists, serpentine, diorite, slickened limestone.	Suess.
Saint Christoval	Quartzite, slate, serpentine, diorite	Guppy (11).
Shortland Islands	Quartz diorite, dacite	Iddings, Marshall.
Tonga Group:		
Eua	(Tourmaline and red garnet in volcanic ash)	Marshall (28).
Isolated islands:		
Bounty	Granite	Speight and Finlayson.
Campbell	Quartz sandstone, conglomerate, old limestone	Marshall (27).
Easter	Granite and slate	Thomson in Marshall (28).
Norfolk	Quartz-bearing tuff fragment	Speight (41).
The Snares	Muscovite granite	Marshall (27).

TABLE II.—PACIFIC ISLANDS DESCRIBED AS VOLCANIC, WITH LIST OF IGNEOUS ROCK TYPES

Islands	Rock Types	Authorities [11]
Admiralty Group (*see Bismarck Archipelago*).		
Anson Archipelago:		
Volcano	....	....
Auckland Group:		
Adams	"Basalts"	Speight and Finlayson.
Auckland	Olivine basalt, olivine diabase, olivine gabbro, diabase, diabase porphyrite, melaphyre, dolerite, hornblende basalt, feldspar porphyrite, augite-olivine andesite, soda trachyte, rhyolite, granite.	Speight and Finlayson, Hartmann, Marshall (28).
Disappointment	Diabase, diabase porphyrite, melaphyre, rhyolite	Speight and Finlayson.
Four others	....	....

[11] The numbers correspond to references in following list. In the cases where no authorities are named, the information has been secured largely from A. Agassiz's coral-reef memoirs, published by the Museum of Comparative Zoology at Harvard University, or from W. T. Brigham's Index to the Pacific Islands, Honolulu, 1900.

Islands	Rock Types	Authorities
Austral (Tubuai) Group:		
Peard		Dietrich.
Rurutu	Olivine basalt	Marshall (28).
Tubuai		Dietrich.
Bismarck Archipelago:		
Admiralty Group:		
Admiralty (Manus)	"Basaltic"	Cohn, Börnstein.
Baluan	"Basaltic"	Cohn, Börnstein.
Lou	Basalt, microgranite	Cohn, Wichmann (56).
Mok Mandrean		Börnstein.
Pom		Börnstein.
Main Group:		
Ambitlé	Basalt, andesite, dacite	Sapper (38).
Anir	Basalt, andesite	Sapper (38).
Lihir (Lir, Gerrit-Denys)	Basalt	Sapper (38).
Macada	Gabbro, quartz diorite, syenite, granite	Sapper (37, 38).
New Hanover	Gabbro, andesites, quartz diorite, syenite, granite	Sapper (37, 38).
New Mecklenburg	Gabbro, andesites, quartz diorite, syenite, granite (gneiss).	Sapper (37, 38).
New Pomerania	Olivine-bearing basaltic andesite, augite andesite, hypersthene andesite, hypersthene-augite andesite, augite porphyrite, augite diorite, diorite porphyrite, dacite, monzonite ("syenite").	Lehmann, Sapper (38).
Twelve others		
Bonin (Ogasawara) Group:		
Buckland (Ami-jima)	Andesite, liparite	Yoshiwara.
Peel (Chichi-jima)	Augite andesite, hypersthene andesite, limburgite	Yoshiwara, Petersen.
Thirty-five others	"Andesitic"	Yoshiwara.
Brumer Group:		
Six small islands		
Caroline Group:		
Kusaie	"Basic lavas"	Südsee Handbuch.
Map-Rumong	Breccia, with fragments of gabbro, amphibolite, pyroxenite, serpentine, wehrlitic types, amphibole syenite, amphibole granite.	Kaiser.
Ponapé	Olivine basalt, nephelite basalt	Wichmann (51, 52), Kaiser.
Truk	Feldspar basalt, amphibolite schist	Krämer.

Islands	Rock Types	Authorities
Yap	Amphibolitic (gabbroid) schist, actinolite schist, talc schist.	Krämer, Kaiser.
Eighteen others		
Chatham Group	Feldspar basalt, andesites, magma basalt, nephelite basalt, trachyte.	Dieseldorff.
Fiji Group:		
Kambara	Olivine andesite	Marshall (28).
Kanathea	Augite andesite	Wichmann (55), Marshall (28).
Kandavu	Augite andesite, hornblende andesite, hornblende-mica andesite.	Wichmann (55), Renard.
Komo	Augite andesite	Marshall (28).
Levuka	Augite andesite	Andrews.
Makongai	Olivine basalt	Marshall (28).
Malolo	Andesite	Marshall (28).
Mango	Olivine basalt, augite andesite, olivine anamesite	Andrews.
Moala	Augite-olivine andesite	Marshall (28).
Munia	Augite andesite, limburgite	Andrews, Marshall (28), Wichmann (55).
Na Solo	Augite-biotite andesite	Marshall (28).
Nairai	Augite andesite	Marshall (28).
Ngau	Olivine basalt	Marshall (28).
Ono	Augite-hornblende andesite	Wichmann (55), Marshall (28).
Ovalau	Augite-hornblende andesite	Wichmann (55), Marshall (28).
Taviuni	Olivine basalt, andesite	Andrews.
Totoya	Olivine basalt, augite andesite	Andrews, Marshall (28).
Vanua Levu	Olivine basalt, augite andesite, hornblende andesite, hypersthene andesite, hypersthene-augite andesite, hornblende gabbro, norite, diorite, quartz andesite, dacite, oligoclase trachyte, quartz porphyry, rhyolite.	Guppy (12).
Vanua Mblavau	Dolerite, augite andesite	Andrews.
Vatu Bulo	Andesite	Marshall (28).
Viti Levu	Olivine gabbro, basalt, diabase, olivine-bearing andesite, augite andesite, augite-biotite andesite, augitite, hornblende andesite, diorite, quartz diorite, amphibolite, trachyte, foyaite, syenite porphyry, quartz porphyry, eurite, granite.	Wichmann (55), Marshall (28).

Islands	Rock Types	Authorities
Vomolailai	Hypersthene-augite andesite	Marshall (28).
Waia	Hornblende andesite	Marshall (28).
Wakaya	Olivine basalt	Marshall (28).
Wi-lai-lai-iwi	Augite-hornblende andesite	Wichmann (55), Marshall (28).
Yanu yanu	Olivine andesite	Marshall (28).
Forty-four others		
Galapagos Group:		
Fifteen islands	"Basaltic"	Gooch, Wolf.
Gambier Group	Olivine-rich, picritic basalt	Lacroix.
Hawaiian Group:		
Hawaii	Olivine basalt, gabbro, wehrlitic gabbro, picritic basalt, augite andesite, trachydoleritic basalt, soda trachyte, nodules of dunite, wehrlite, and lherzolite.	Cross, Daly.
Kauai	Olivine basalt, olivine-free basalt, oligoclase gabbro (kauaiite), limburgite, nephelite-melilite basalt.	Cross.
Laysan	Olivine basalt, trachytic type	Cross.
Maui	Olivine basalt, olivine diabase, melilite-nephelite basalt, soda trachyte, picritic basalt, trachyandesite.	Cross.
Molokai	Olivine basalt, basaltic andesite, nephelite basantoid, olivine diabase.	Cróss, Lindgren.
Necker	Olivine basalt	Möhle, Cross.
Oahu	Olivine basalt, bronzite basalt, gabbro, olivine-free basalt, nephelite basalt, nephelite-melilite basalt, tephrite, limburgite.	Cross.
Hervey (Cook) Group:		
Aitutaki	Dolerite, nephelite basalt	Marshall (23).
Mangaia	"Basaltic"	Marshall (25).
Rapaka	Nephelite basalt	Iddings.
Rarotonga	Basalt, dolerite, feldspar-free phonolite (nephelinite).	Marshall (23).
Horne Group:		
One island		Brigham.
Juan Fernandez Group:		
Masafuera	Olivine basalt, picritic basalt, basanite, phonolitic trachyte.	Quensel.
Masatierra	Olivine basalt, olivine-poor basalt, gabbroid type, picritic basalt, olivine nodules.	Quensel.

Islands	Rock Types	Authorities
Kermadec Group:		
Curtis		Oliver.
Dayrell	Andesite	Oliver, Speight (40), Thomas.
French Rock	Olivine andesite	Oliver.
Haszard		Oliver.
Macauley	Olivine basalt, andesite	Oliver, Speight (40).
Meyer	Tuff fragments of basalt, augite andesite, and granite.	Oliver, Speight (40), Thomas.
Napier	Augite-hypersthene andesite	Oliver.
Sunday	Olivine basalt, olivine-poor basalt, augite andesite, andesitic basalt, augite-olivine andesite, olivine andesite, tuff fragment of hornblende granite.	Oliver, Speight (40), Thomas.
Loyalty Group:		
Maré		Marshall (28).
Mariana Group:		
Alamagan	Augite andesite bearing hypersthene and olivine	Iddings.
Farallon de Pajaros	Augite andesite (basic)	Kaiser, Marshall (28).
Saipon	Amphibole-bearing augite andesite	Kaiser, Marshall (28).
Thirteen others		
Marquesas Group:		
Hiva Ova	"Basaltic"	Marshall (28).
Nukuhiva	"Basaltic," gabbro, probably olivine basalt, leptynite, biotite trachyte.	Marshall (28), Iddings.
Uapu	"Basaltic"	Marshall (28).
Eight others		
New Caledonia	Diorite, syenite, trachyte, serpentine	Réclus.
New Hebrides Group:		
Ambrym	Olivine basalt	Marshall (26).
Aneityum	Olivine basalt	Mawson.
Aoha	Olivine basalt	Marshall (28).
Efate	Basalt, andesite	Frederick.
Epi	Pyroxene andesite	Mawson.
Espiritu Santo	Basalt, olivine andesite, pyroxene andesite, hornblende andesite.	Mawson.
Futuna	Feldspar basalt	Wichmann.
Gaua	Basalt	Mawson.
Leleppa	Hypersthene andesite	Mawson.

Islands	Rock Types	Authorities
Makura	Dolerite	Teall (44).
Malekula	Pyroxene andesite, hornblende andesite, uralite porphyry.	Mawson.
Mau	Basalt porphyrite	Mawson.
Tanna	Basaltic andesite, augite andesite	Frederick, Liversidge.
Tongoa	Basalt, augite andesite	Teall.
Ureparapara	Basalt, andesite	Mawson.
Vanua lava	Olivine basalt, pyroxene andesite	Mawson.
Twenty-five others	....	....
Paumotu (Tuamotu) Group:		
Pitcairn	Hypersthene andesite, "basaltic"	Iddings, Marshall (28).
Pelew Group:		
Baobeltaob	Augite andesite	Oebbeke, Wichmann (51).
Korror	Augite andesite, hypersthene andesite	Oebbeke, Kaiser.
Malakal	Augite andesite, syenitic granite	Oebbeke, Marshall (28).
Negarekobasanga	Augite andesite	Oebbeke.
Rallap	Feldspar basalt	Oebbeke.
Samoan Group:		
Apolima	Nephelite basalt	Marshall (28).
Aunuu	Nephelite-bearing trachydolerite	Marshall (28), Iddings.
Manua	....	Marshall (28).
Ofu	Basalt	Marshall (28).
Olosega	Basalt	Marshall (28).
Savaii	Olivine basalt, picritic basalt, olivine-poor basalt, nephelite basalt, nephelite basanite, phonolite.	Weber, Marshall (28).
Tau	Basalt	Marshall (28).
Tutuila	Feldspar basalt, andesitic basalt, trachydolerite, phonolitic trachyte, limburgite.	Weber.
Upolu	Feldspar basalt, haüynite-bearing nephelite basanite, trachydolerite, limburgite.	Weber.
Santa Cruz Group:		
Seven islands	....	....
Society Group:		
Borabora	....	....
Huaheine	Basalt, phonolite	Marshall (28), Iddings.
Moorea (Murea, Eimeo)	Olivine basalt, phonolite	Marshall (28).
Raiatea	Basalt, trachytoid phonolite	Marshall (28).

Islands	Rock Types	Authorities
Tahaa	Dolerite	Marshall (28).
Tahiti	Olivine basalt, picritic basalt, picrite, essexitic gabbro, theralite, haüyne-hornblende rock, nephelitic monzonite, nephelite syenite, phonolite, haüynophyre, tinguaite, camptonite, syenite, wehrlite, gabbro.	Lacroix, Marshall (24).
Six others		
Solomon Group:		
Bougainville	Augite andesite, pyroxene andesite, hornblende andesite, dacitic rhyolite.	Sapper (39).
Buka	Andesitic	Sapper (39).
Faro (Fauro)	Dolerite, augite andesite, hornblende andesite, quartz andesite, diorite, quartz porphyry, quartz felsite.	Guppy (11).
Florida Cluster	Augite andesite, hornblende andesite, diallage-serpentine rock, trap-granulite, quartz diorite, quartz porphyry, dacite.	Guppy (11).
Gizo Cluster	Basalt, hypersthene andesite	Watts and Newton.
Guadalcanar	Dolerite, gabbro, diorite, peridotite, serpentine	Guppy (11).
Illina	Hornblende andesite	Guppy (11).
Isabel	Serpentine	Guppy (11).
Mono (Treasury)	Dolerite	Marshall (28).
Murray	Augite andesite	Guppy (11).
Nabolo	Andesite-pitchstone	Guppy (11).
Oima	Hornblende andesite	Guppy (11).
Piedu	Augite andesite, porphyrite, hornblende-mica andesite.	Guppy (11).
Rubiana (New Georgia)	Olivine basalt, augite andesite, hornblende andesite, augite trachyte.	Watts and Newton.
Saint Christoval	Dolerite, gabbro, diabase, diorite, serpentine, diallage rock.	Guppy (11).
Santa Anna	Dolerite, gabbro, hornblende trachyte	Guppy (11).
Simbo (Eddystone, Narovo)	Augite andesite, hypersthene andesite	Guppy (11), Watts and Newton.
Tanna	Diorite	Marshall (28).
Ugi	Dolerite	Guppy (11).
Six others		

Islands	Rock Types	Authorities
Tonga Group:		
Eua	Augite andesite, hypersthene andesite	Marshall (28).
Falcon (shoal)	Augite andesite	Lister and Harker.
Lofango	Andesite	Teall and Newton.
Lalona	Hypersthene andesite	Teall and Newton.
Mango	Andesite	Teall and Newton.
Mo 'unga 'om	Augite andesite, hypersthene andesite	Teall and Newton.
Niuafou	Basalt, augite andesite	Cohen, Wichmann (53).
Tofua	Augite andesite	Marshall (28).
Fifteen others		
Volcano Group:		
Sulphur	Olivine andesite, biotite-bearing augite andesite	Petersen.
Three others		
Isolated islands:		
Antipodes	Olivine basalt	Speight and Finlayson.
Bounty	Granite	Speight and Finlayson.
Campbell	Dolerite, gabbro, feldspar basalt, melilite basalt, soda trachyte, phonolite.	Marshall (27).
Clipperton	Trachyte	Teall (45).
Easter	Basalt, augite andesite, trachytic glass, olivine nodules with nephelite.	Vélain, Iddings.
Hoflawa and Uea		Gardiner.
Lord Howe	Basalt, diabase	Marshall (28), Iddings.
Matthew		Brigham.
Norfolk	Basalt, one quartz-bearing fragment in tuff	Marshall (28), Speight (41).
Rotuma	Olivine basalt, dolerite	Gardiner.
Sala y Gomez		Agassiz.
The Snares	Muscovite granite	Marshall (27).

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TABLE III.—NUMBER OF ISLANDS FROM WHICH ROCK SPECIES IS REPORTED

Class	Names given by authors	Number of islands	
1. Representing feldspar-basalt magma.	Olivine basalt	32	
	Feldspar (plagioclase) basalt	16	
	"Basalt"	26	
	Dolerite	14	
	Melaphyre	2	
	Olivine anamesite	1	
	Basalt porphyrite	1	
	Diabase	5	
	Olivine diabase	3	
	Diabase porphyrite	2	
	Gabbro	13	
	Olivine gabbro	2	
	Norite	1	
			118
2. Representing transitions between Classes 1 and 3.	Andesitic basalt	2	
	Basaltic andesite	3	
	Olivine andesite	6	
	Augite-olivine andesite	3	
			14
3. Representing pyroxene-andesite magma.	Augite andesite	37	
	Hypersthene andesite	11	
	Augite-hypersthene andesite	5	
	Pyroxene andesite	5	
	Augite-hornblende andesite	4	
	Hornblende andesite	12	
	"Andesite" (probably pyroxenic)	16	
	Augite porphyrite	1	
	Augite diorite	1	
	Diorite porphyrite	1	
	Feldspar porphyrite	1	
	Porphyrite	1	
	Diorite (in part ?)	7	
			102
4. Representing transitions between Classes 1 and 5.	Picritic basalt	7	
			7
5. Representing peridotitic magma.	Picrite	1	
	Dunite	2	
	Peridotite	1	
	Wehrlite	4	
	Lherzolite	1	
	Diallage rock	2	
			11
6. Representing transitions between Classes 1 and 7.	Trachydoleritic basalt	1	
	Essexitic gabbro	1	
			2
7. Representing "alkaline" magmas.	Trachydolerite	2	
	Nephelite basalt	7	
	Nephelite-melilite basalt	3	
	Nephelite basantoid	1	
	Nephelite basanite (bearing haüynite)	2	
	Basanite	1	
	Melilite basalt	1	
	Haüynite-hornblende rock	1	
	Haüynophyre	1	
	Magma basalt	1	

Class	Names given by authors	Number of islands	
7. Representing "alkaline" magmas.	Limburgite (subalkaline ?)	6	
	Theralite	1	
	Tephrite	1	
	Monzonite	1	
	Nephelite syenite	1	
	Foyaite	1	
	Nephelite monzonite	1	
	Syenite (in part ?)	6	
	Trachyte	9	
	Soda trachyte	6	
	Phonolite	6	
	Nephelinite	1	
	Trachyandesite	1	
	Syenite porphyry	1	
	Tinguaite	1	
	Camptonite	1	
		——	64
8. Quartzose rocks	Granite	12	
	Rhyolite or liparite	5	
	Quartz felsite	1	
	Quartz porphyry	4	
	Quartz diorite	5	
	Quartz andesite	2	
	Dacite	3	
		——	32
9. Residual types	Hornblende basalt	1	
	Hornblende gabbro	1	
	Bronzite basalt	1	
	Hornblende-mica andesite	2	
	Augite-biotite andesite	2	
	Trap-granulite	1	
	Kauaiite	1	
	Pyroxenite	1	
	Augitite	1	
		——	11

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DOMINANTLY FLUVIATILE ORIGIN UNDER SEASONAL RAINFALL OF THE OLD RED SANDSTONE [1]

BY JOSEPH BARRELL

(Presented before the Society December 28, 1915)

CONTENTS

INTRODUCTION

The Devonian system is represented in the British Isles, except in the extreme south of England, by a thick series of red sandstones, shales, and conglomerates. Red sandstone is the predominate outcropping rock, the colors of which range from light red to deep chocolate brown, but in places exhibit green, yellow, gray, and mottled tints. The series of for-

[1] Manuscript received by the Secretary of the Society January 25, 1916.

mations which make up this system have been known collectively since the early days of geologic science as the Old Red Sandstones.

In Cornwall and southern Devon the Devonian is represented by slates, grits, volcanic materials, and thick masses of limestone holding marine fossils; but in Ireland, Wales, Scotland, and the contiguous parts of England the formations of equivalent age constitute the totally different facies, the Old Red Sandstones. These show their contrast not only in lithologic character, but in their barrenness of marine fossils. The Devonian age of these rocks was in fact only known at first because of their intercalation between the formations of the Silurian below and Carboniferous above, both identifiable by their marine fossils.

What, then, were the geographic and climatic conditions which controlled the nature of the Old Red Sandstone deposits? The question is raised to a higher degree of interest because the formations, though barren of fossils of the sea, yet hold at certain horizons an abundant and varied fauna of ostracoderms and fishes, the latter including forms which lead toward the amphibians.

The footprints of amphibians can be traced back to the close of the Devonian period. It was in the Devonian that they doubtless rose from air-breathing fishes. We must look, then, for our own ancestral tree within certain families of these Old Red Sandstone fossils. Was it within the physical conditions which determined the nature of the Old Red Sandstone, or was it from the open sea that certain fishes grew to breath the vivifying air, to crawl on the solid land, and inaugurate from such humble beginnings that dynasty of terrestrial vertebrates which through all after ages was to lead in the march of evolution and rule over the living things of earth? It can be shown with high probability that it was from the faunas of the Old Red Sandstone, molded in adaptation to the physical and climatic conditions which surrounded them, that the amphibians arose.

Studies in evolution are commonly regarded as within the field only of comparative anatomists, either students of fossils or of living forms; but the ancient life history of the earth embraces not only the organic remains, as shown by the fossils, but a study of the environment which surrounded them and to which their life activities made efficient response. The analysis and evaluation of this environment is as important in the complete mosaic of knowledge as is a minute description of the fossils of successive faunas. Yet the student of fossils is not, by virtue of his knowledge of fossils alone, qualified to interpret fully the life surroundings of those former organisms. For this he must draw on his knowledge of physical geology and the habitats of living forms. He must be able to

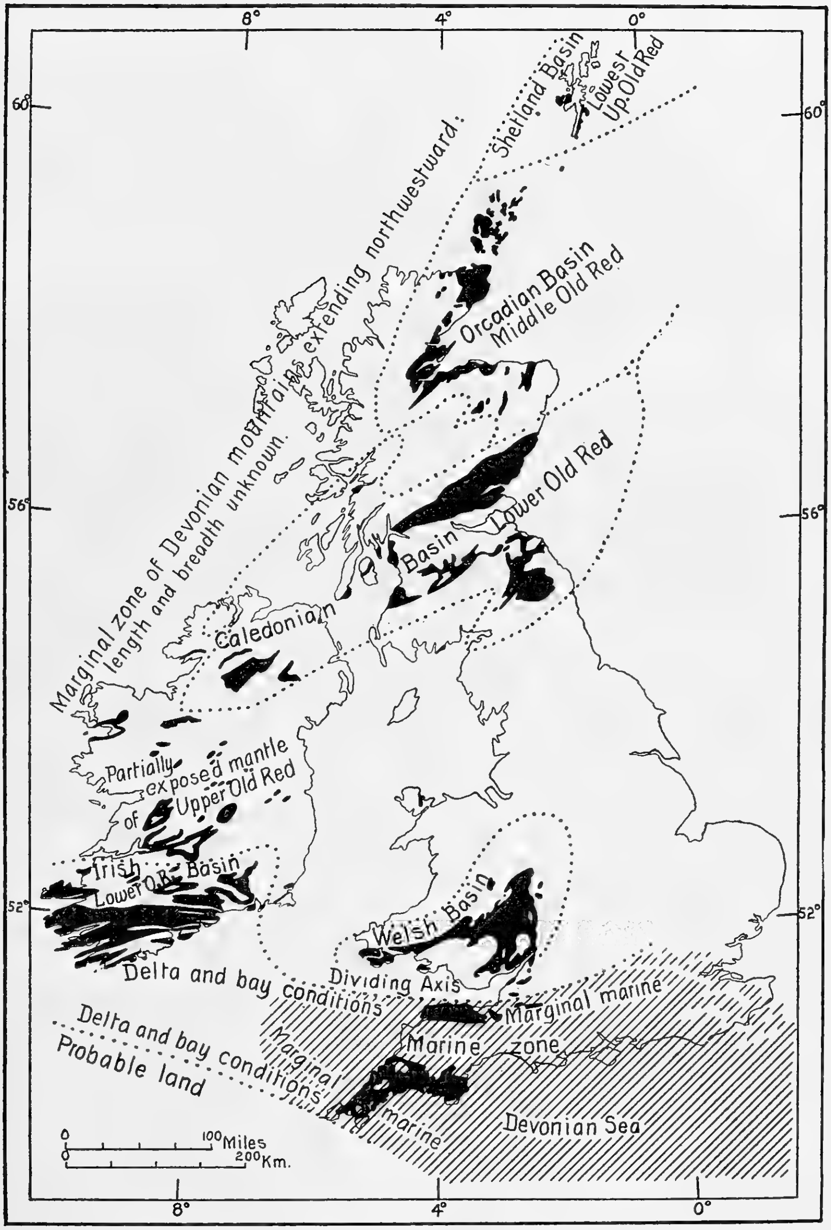

FIGURE 1.—*Geography of the British Isles in Devonian Time*

The loci of deposition of the Old Red Sandstone of the Lower and Middle divisions are shown and are interpreted as river basins, not as lakes, though subordinate lacustrine phases would attend fluviatile deposition. The outcrops of Devonian formations are shown in black.

interpret the meaning of the sediments which envelop the fossil—sediments which are the record of the environment of the living animal. There is a side, then, to the ancient life history of the earth which belongs to physical geology. It is as a physical geologist, and not as a paleontologist, that the writer has taken up the present problem, but with the purpose of showing the relations between the environment and the evolution of air-breathing vertebrates.

This article was prepared in essentially its present form in 1907 and made the basis of a paper on the causes of the evolution of land vertebrates presented orally on December 26, 1907, to the American Society of Vertebrate Paleontologists.[2] It was withheld from publication because the writer hoped to make a personal field study of the Old Red Sandstone formations of the British Isles. These plans did not materialize, but in the meantime he has published a paper on the somewhat similar deposits of the Appalachian geosyncline,[3] and he has also published a number of critical studies on the interpretation of the sedimentary record. A broad knowledge of the geologic problems involved and the correctness of the criteria of interpretation are as important for drawing conclusions as are the local facts to be interpreted; this is the basis of judgment which has led to a decision to publish the following study on the Old Red Sandstone, chiefly because of its bearings on the problems of the evolution of the amphibians.

The descriptions are taken from various memoirs, but experience shows that the features which serve best as criteria of origin have been often overlooked in the field or left undescribed in their reports by the older geologists, partly because of a lack of appreciation of their significance, partly because, even when present, they are often as difficult to find as fossils and require similar painstaking search of fresh exposures.

The central conclusion reached in this paper is that the Old Red Sandstone formations were not deposited in lakes or estuaries, nor are they of desert origin. The analysis of their characteristics and comparison with sediments now forming determines them to be river deposits accumulated in intermontane basins. This is a kind of sedimentation not now found in the British Isles. For a close analogy one may turn to the basin deposits of the western United States laid down in the Tertiary period between the growing ranges of the Cordillera. This reinterpretation of the Old Red Sandstone of the British Isles is in line with that which has gone forward in America during the past fifteen years in regard to the

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[2] Abstract in Science, vol. xxvii, 1908, pp. 254, 255.

[3] The Upper Devonian delta of the Appalachian geosyncline. Amer. Jour. Sci., vol. xxxvi, 1913, pp. 429-472; vol. xxxvii, 1914, pp. 87-109, 225-253.

mode of origin of the continental Tertiary deposits: once looked on as deposited in lakes greater in area than any now existing on the earth, they are now regarded as accumulations made chiefly on river plains. Such a reinterpretation for the Old Red Sandstone involves radical changes in the conceptions of Devonian geography—no less a change than the substitution of land surfaces, occasionally flooded, as a replacement in the mental vision of wide and permanent bodies of water. If the new interpretation is well founded, it means that such terms as "Lake Caledonia" and "Lake Orcadie" should be turned into the "Caledonian and Orcadian basins."

Prevailing Views regarding Conditions of Origin

Hugh Miller regarded the Old Red Sandstone as a marine deposit, reaching this conclusion by direct comparison of the structures of the solid rocks with near-by tidal deposits now being made. It was soon perceived, however, by British geologists that the sediments and organic contents were of different types from the obviously marine Devonian strata to the south. These distinctions led Godwin-Austen in 1855 to a view, previously maintained by Dr. John Fleming, that the Old Red Sandstone was laid down in great fresh-water lakes or inland seas. This interpretation soon became generally accepted. During the next generation the geologist who gave most thorough study to the subject was A. Geikie. He separated the Old Red Sandstone into several basins of deposition. According to Geikie, Lake Caledonia stretched across central Scotland, and within it were deposited a maximum thickness of perhaps 20,000 feet of strata. Other basins were occupied by the Welsh Lake, Lake Cheviot, Lake Lorne, and Lake Orcadie. In the latter area there are exposed as much as 16,000 feet of strata. These views are developed in his paper of 1877-1878[4] and are summarized in his textbook in 1903.

Macnair and Reid in 1896 give, however, what they regard as reasons for holding that the fresh-water lake hypothesis of origin is "utterly untenable" and come back to the view of Hugh Miller, that the Old Red Sandstone is marine.[5]

In 1904 Goodchild published a paper which embraces the following statements:

"There is no satisfactory reason for regarding any of the Scottish rocks of Devonian age as of marine origin; and, on the other hand, there is much to be said in support of the view that they were all formed under continental con-

[4] On the Old Red Sandstone of western Europe. Trans. Roy. Soc. Edinburgh, vol. xxviii, pt. ii, pp. 345-452.

[5] Geol. Mag., Decade 4, vol. iii, 1896, pp. 106-116, 217-221.

ditions, and under conditions of climate which, though doubtless varying much from time to time, were yet, on the whole, characterized by an annual rainfall decidedly below the average in amount. It is this feature which has imparted a common character to the whole of this series of rocks."

"The fauna of the Upper Old Red consists almost exclusively of fishes which probably found their way into the sediments from the rivers of upland origin, whose waters were dissipated by the excessive evaporation when they reached the lowland area."

"As regards the mode of origin of the Old Red of the Caledonian area (Lower Old Red), there appears to be evidence of a satisfactory nature that the whole of this vast formation was accumulated under continental conditions, partly in large inland lakes, partly as torrential deposits of various kinds, partly as old desert sands, and partly as the result of extensive volcanic action." [6]

With these views the present writer is in accord, except that he would give first place to true fluviatile deposition, spreading sediments on broad and flat river plains, a form of deposition intermediate between torrential and lacustrine and yet quite distinct from either. It is one which is not, however, specifically mentioned by Goodchild.

In 1907 the writer, unaware at the time of Goodchild's paper, presented the evidence showing the wide-spread development of floodplain deposits in the Old Red Sandstone and the presence of a fluviatile piscine fauna. This view was, however, only published at the time in brief abstract.[7]

In 1908 Walther published a volume entitled "Geschichte der Erde und des Lebens." In this is a chapter on the Devonian continent which lay northwestward from central Europe and which included Scandinavia and the British Isles. He includes in this same continent Greenland and the Canadian Shield. The name he gives to it is "The Old Red Northland." The chapter, pages 254 to 271, is largely of general statements and draws an analogy between the climatic and sedimentary conditions of this continent and the present interior of Asia and Australia. Walther states, for example (page 259):

"The northern Devonian land consisted of many parts. Many lines of fracture passed through the older mountain structures. Some of the principal lines extending northeast are yet visible. Often the sandstones lie on the steep-walled cores of the ancient mountains, filling up deep basins, so that great regions of deposition, as the 'lakes' of Orcadie, Caledonia, and Lorne, can be distinguished. One should not conceive under that term, however, enduring bodies of water, but rather wide basins surrounded by mountains limited by temporary sheets of water, water which converged to shallow lakes of variable

[6] J. G. Goodchild: The older Deutozoic rocks of North Britain. Geol. Mag., Decade 5, vol. i, 1904, pp. 591-602.

[7] F. B. Loomis: The American Society of Vertebrate Paleontology. Science, vol. xxvii, Feb., 1908, p. 254.

area and depth. These would dry out until the next period of rains filled them."

"We attain therefore the conception that the northern continent, already in the Upper Cambrian, again in the Upper Silurian, and further through the whole of the Devonian period, even into the Lower Carboniferous, possessed a hot desert climate whose dry periods were broken only seldom by the downpours of thunder-storms."

Walther considers the red colors as original to the sediments. From this he derives his name of the Old Red Northland. There has been presented, however, no evidence that the original sediments had the present color tones of the solid rocks. Dehydration and change in color of the iron oxide commonly accompany thorough cementation. Neither has there been presented evidence of pronounced wind action or the existence of evaporation deposits. It seems, therefore, that this picture of a desert climate is overdrawn. A truer view may center on a semi-arid climate and a land whose character lies half way between the permanent lakes of the British geologists and the permanent deserts of Walther.

Jukes-Browne published in 1911 a revision of his volume on "The Building of the British Isles." In the chapter on the Devonian period he discusses the evidence which goes to show that the basins of Old Red deposition were originally much wider than their present limits. The small areas he regards as remnants isolated by erosion. The difference in the faunas and floras of the Caledonian and Orcadian areas must therefore, as Traquair has argued, be due to shifting of subsidence and consequent shifting of deposition during the course of the Devonian, and not to the maintenance of permanent mountain barriers between them. Jukes-Browne recognizes Goodchild's arguments for a climate at times desert in character, but refers to the areas of deposition as lakes. These lakes, under his conception of greater area of deposit, become in fact fresh-water seas of far-reaching extent. Thus the essentially lacustrine conception is maintained and fluviatile deposition is not accorded a place of importance.

In America the trend of opinion in regard to the proper interpretation of the Old Red Sandstone has been increasingly in the direction of ascribing a larger importance to fluviatile deposition, but these views are mostly unpublished and have naturally therefore carried no weight in British opinion. The earliest American expression of view, in what is here regarded as the right direction, was, so far as the writer is aware, that by T. C. Chamberlin in 1900. This pioneer in geologic thought, in a paper of philosophic nature on the habitat of the early vertebrates, suggested that the Old Red Sandstone was deposited under conditions not unlike

those now found in the Great Valley of California. There was, however, no presentation of detailed argument. Since then Grabau and the present writer have independently and repeatedly written on the part which the rivers of later Paleozoic time have played in continental deposition, dealing chiefly with the rivers flowing westward from Appalachia. The arguments for them apply with variations to the British deposits also. Grabau studied the latter some years since, in the field, and has stated that he is in full agreement with the conclusions of this paper in regard to the dominantly fluviatile character of the sediments. Approaching the subject from another side, Doctor O'Connell has written an extensive paper, entitled "The Habitat of the Eurypterida," to be published as one number of the Bulletin of the Buffalo Society of Natural Sciences. She has treated the subject of the Old Red Sandstone at some length, predominantly, though not exclusively, from the standpoint of the faunal evidences. The conclusion is reached in her paper that the eurypterids were preeminently a fluviatile fauna, and their associations in the Old Red Sandstone show that the latter is dominantly fluviatile. This is a supplemental line of evidence, and she states as a conclusion:

> "I am convinced that the detailed study of the geological and geographical distribution of the eurypterids (and I think the fishes, also) will do more than anything else to prove that they lived in the rivers, and that many peculiar deposits will be easily explained as of floodplain or delta origin when the importance of fluviatile deposition is once realized." [8]

In the Textbook of Geology by Pirsson and Schuchert, published 1915, the view is adopted by Schuchert that the Old Red of Scotland is probably wholly continental. The opinions of Goodchild and Walther are quoted, but the basins, following the British custom, are still spoken of as lakes; and it is stated that Lake Orcadie may have extended as an estuary northeast to Christiania, in southern Norway, and possibly even to Petrograd, in Russia. The south Irish deposits are regarded by Schuchert as marine.*

Criteria as to Modes of Origin of Sediments [9]

It is evident from the preceding review of opinions that a sound conclusion regarding the geography of the British Isles during the Devonian period depends not so much on the accumulation of new facts of observa-

[8] Personal communication.

* Pages 715-717, 1915.

[9] This topic is essentially a summary of such arguments as bear on the present problem from articles published by the writer in the Journal of Geology and Bulletin of the Geological Society of America. If this article dealt only with American geology, a very brief restatement of these criteria would doubtless suffice; but as the subject in hand is

tion as on the soundness of the principles of interpretation. Especially important is the quantitative evaluation of the significance of various characteristics, since it is true that some lacustrine conditions will accompany fluviatile deposition and *vice versa.* Loose sand may be subjected to wind action and build dune structures even in humid climates. Semi-aridity is a condition which will permit the development of features which are also found in the most arid climates, and yet semi-aridity does not exclude the existence of abundant life. Semi-aridity is more widely associated with seasonal rainfall than with deficient precipitation throughout the year. The rainfall may be as abundant during the rainy season as that of truly humid climates. Fluviatile deposition is vitally distinct from either lacustrine or desert conditions, and semi-aridity is a type of climate equally distinct from either normally humid climates, on the one hand, or arid climates on the other. Yet it is fluviatile deposition under a semi-arid climate which is here held to have characterized the laying down of the Old Red Sandstone. This interpretation is essentially new and lies between that of the lakes of Austen and Geikie and the deserts of Walther and Goodchild.

As stated to a considerable degree in a previous paper,[10] many features from which an observer may gain an impression as to the mode of origin of a deposit are really not definite proofs. Thus ripple-marked, cross-bedded, and fossil-barren deposits may be developed either beneath a permanent water cover or on river plains, though doubtless the quantity and quality of their development differ in the two cases.

Red beds have been regarded by some, because of their color, as evidences of terrestrial deposition; by others, of seas barren of life. Again, they have been cited as indications of a deeply decayed regolith, of a humid climate, or of aridity. The present writer holds that redness in rocks may in fact accompany any of these conditions, and is not therefore a criterion by itself of any one.[11]

Mud-cracks and conglomerates have been cited usually as evidences of ancient tidal flats and beaches, but are now observed to occur chiefly in river deposits of continental interiors. Those formed in the littoral zone, furthermore, except on the fronts of deltas, are rather unfavorably situ-

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the mode of origin of formations in the British Isles and the special feature of the paper is the application of these criteria, it seems desirable to give a fuller review of the principles on which they rest. This is because it is hoped that the subject will be of interest to British geologists, to many of whom the papers on which this discussion rests may not be readily accessible.

[10] Joseph Barrell: The Upper Devonian delta of the Appalachian geosyncline. Amer. Jour. Sci., vol. xxxvi, 1913, pp. 436-440.

[11] Relations between climate and terrestrial deposits. (The climatic significance of color.) Jour. Geol., vol. xvi, 1908, pp. 285-294.

ated for geological preservation, and are to be distinguished by associations which are commonly absent in ancient examples.[12] Thus it seems clear that it is the character, the quantitative development, and associations of the stratigraphic features, as well as the nature of the entombed organic remains, which are significant rather than their mere occurrence.

In general, traditional criteria are liable to lead into error, because they become accepted as axioms and are applied without further thought. They lag behind the development of a science, whereas the very word "research" implies the necessity of continually testing the correspondence of the images of science with nature.

Attention may now be turned to what may be regarded in the present state of knowledge as fairly definite criteria, which will be of use in discussing the origin of the Old Red Sandstone formations.

A fresh-water origin for these deposits will be assumed as established and accepted by practically all geologists, but many are accustomed to thinking of the presence of fresh-water faunas and the absence of marine organisms as implying nothing more than land-locked, brackish-water bodies, perhaps fresh near their heads, as seen in Chesapeake Bay and the Baltic Sea. The deposits, following this conception, would be called estuarine. If clearly separated by a land barrier from the open ocean, then the deposits have in the past been usually regarded as lacustrine and taken to imply the former existence of great fresh-water lakes or inland seas. True estuaries must have been of limited development, however, in past times, since, like lakes, they are temporary features and are made by a rising sealevel against a land surface previously dissected by erosion. Deposits made in nearly landlocked water bodies, like the Baltic, should rather be called "bay formations." Where there is some intermingling, interfingering, and gradation of marine and fresh-water deposits with their respective faunas, the relation which is implied is commonly that of the shore of a delta. Such a shore is marked by shifting growth, by wide advances and retreats, and the inclosure of marginal lagoons of various degrees of salinity.[13]

In the Old Red Sandstone of the British Isles these marginal delta phases are not so important as in the Devonian on the continent of Europe and in eastern North America. They do occur, however, in northern Devon and in southern Ireland. The problem of the British Old Red Sandstone really resolves itself into the discrimination between true

[12] Joseph Barrell: Mud-cracks as a criterion of continental sedimentation. Jour. of Geology, vol. xiv, 1906, pp. 524-568.

[13] Joseph Barrell: Criteria for the recognition of ancient delta deposits. Bull. Geol. Soc. Am., vol. 23, 1912, pp. 377-446.

lacustrine deposits on the one hand and terrestrial deposits on the other. Terrestrial deposits may in turn be classified into fluviatile, torrential, glacial, and eolian.

Lakes are characterized by being permanent water bodies as measured by the changes of decades, centuries, or longer periods. Constructional alluvial plains, on the other hand, are largely turned into temporary lakes during the annual season of flood and give thereby some similarities to lacustrine deposition, but are drained during the dry season, and their life is that of the land.

In the upper part of the alluvial plains the river grades are steeper, the waste coarser, the flooded condition more brief. The marks of subaerial exposure are more dominant, as seen especially in the greater oxidation of sediments, giving red rocks on cementation, and the greater paucity of fossils. In the lower part of the plains, on the contrary, the grades are flat, commonly less than a foot per mile; the sediments are finer and more impervious to ground waters; the flooded condition is of greater annual duration, and in playa lagoons and swamps may in fact be permanent for a series of years. The rivers, owing to minor climatic fluctuations, will during one series of years entrench themselves and minimize the flooding of the plains. During other series of years they may rise high, flood their plains broadly and for longer periods, depositing an excess of waste. The channels also shift and the natural levees are built upward to above the level of all save the highest floods. In the same geologic section, therefore, river action is characterized by variable relative durations of exposure to flood waters and exposure to the air.

True lake conditions, then, as distinguished from the temporary and subordinate water bodies connected with fluviatile deposition, are characterized on the margins by wave-formed sands and conglomerates, as distinguished from the current deposits of streams. The basins of permanent lakes must be sufficiently deep to have the greater portion of their bottom below wave base. The shore deposits of lakes will consequently, for any one horizon, be essentially marginal, and the greater area of the lake will be marked by clays and fine silts deposited from suspension. Regular, even lamination, giving rise to paper-thin shales, will be typical. Lenses of sand, but especially beds of conglomerate, will be absent. The presence or absence of sand is in itself, however, of doubtful value as a criterion. Conglomerates, on the other hand, when they are of wide-spread occurrence, are of the highest significance.

For floodplain conditions there are a number of definite criteria depending on the texture of the deposit and the climate under which they are laid down. Where the deposits are argillaceous and the climate is

one subject to dry seasons, the most important criterion consists of marks of subaerial exposure, developed both *broadly* and *vertically* through mechanical sediments. These consist chiefly of mud-cracks, rain-prints, and impressions of roots *in situ*. Where these occur in such relations they seem to show conclusively a terrestrial origin, and not to represent the littoral facies of a marine or lacustrine formation. Not only, as stated previously, does the shore form at any one time but a narrow border to the accumulating mantle, but, except on the front of an advancing delta, it is commonly a region of erosion rather than of accumulation. Tidal flats are furthermore flooded and drained twice per day, with the result that they are always limited in width and are cut by deep channels. These conditions are quite distinctive from those which are found inland. For over deltas and playa basins, on the contrary, every part is alternately covered by water and by air for considerable periods of time. Where the climate is suitable mud-cracking is developed habitually and on a broad scale.

Mud-cracking in chemical sediments—that is, in limestones, most typically the impure or "water-limes"—must, however, be distinguished in significance from the cracking in claystones. Lime carbonate is carried in solution and its deposition as limestones requires a comparative absence of sand and clay, the mechanical deposits carried by rivers and by waves. The solutions, to have sufficient concentration, may come from permanent water bodies, either lakes or seas. The deposit, therefore, comes not from the direction of the land, but from the direction of the water. The cracking goes on between the extreme levels of high and low water, and the slight shifting of level is not a tidal, but at least a seasonal, phenomenon. Such mud-cracking of limestones is a playa phenomenon, and especially in certain earlier ages, when the lands were baseleveled and lay awash with the sea, broad areas seem to have been at times marine playas. Marine fossils, often of depauperated kinds, occur sometimes in mud-cracked limestones. The nearest approach in the modern world is found, doubtless, in the Rann of Cutch, an area of 10,000 square miles south of the Indus, flooded by the sea for a part of the year, during the period of onshore monsoon winds.

In the detection of mud-cracks in ancient formations reasonable care must be used to avoid mistaking for them a polygonal cracking of the rock arising after its solidification. The two, however, are readily distinguished. True mud-cracks always have a filling; the polygons are irregular, but do not show irregularity constant in one direction. True mud-cracks, although easily separated from simulated features, are, however, often very difficult to detect, as the filling may be identical in nature

with the original stratum; and weathering, furthermore, destroys such strata very rapidly unless the shales are interlaminated with sandstones. Rain-prints must be separated from the pits made by escaping marsh gas and are more usually marked by a spattered surface of the mud than by a few concave depressions. Root-marks should show a branching pattern and finer tendrils given off from the larger marks. Footprints may be very obscure, but the test in that case is the regularity of recurrence on the stratum, owing to the stride of the animal and its regularity.

Finally, a criterion of special application to much of the Old Red Sandstone deposits is found in the nature of the conglomerates.

Conglomerates now forming which are both thick and wide-spread, as Blanford and Bonney have shown, are observed to be of fluviatile and not littoral origin. This is because rivers are able to carry gravels far out over a subsiding river plain; but the waves, on the contrary, tend to keep gravel banked in the zone of the shore. During an advance or retreat of the sea, basal conglomerates may be widely spread, but they are thin and often wanting, reaching their greatest development among islands or along an irregular rocky shore able to withstand the waves for some time during a rising sea. A maximum limit to wide-spread basal marine conglomerates seems to be 100 feet, and therefore broad conglomerate formations of greater thickness are evidences of terrestrial accumulation.[14]. They may, of course, be of terrestrial origin also when thinner and more limited; but in that case, so far as these criteria determine, they may also be marine or lacustrine.

Other characters which are, under certain circumstances, of importance are found in the detailed structures and associations of the conglomerate beds. Gravels which have been carried considerable distances by powerful rivers may be as well sorted and as thoroughly worn as are the waveworn gravels of the shore, but weak rivers carry their debris especially during great floods. Coarse and fine are swept along together; sorting and wear are less perfect; streaks of gravel are swept out from the basin margins and intercalated with dominant sandstones and even with beds of shale. River gravels are shingled by the currents so that the longer diameters of the pebbles dip upstream, giving a faint appearance of false bedding, which on the average, unlike the false bedding of sandstone strata, dips toward the basin margin. Shore gravels, on the other hand, are developed parallel to the shore. The onshore waves have a greater force than the undertow and the shingling dips away from the shore, or runs out laterally from protruding headlands.

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[14] Joseph Barrell: Some distinctions between marine and terrestrial conglomerates. Abstract. Bull. Geol. Soc. Am., vol. 20, 1908, p. 620.

Lastly, from a larger point of view, shallow-water deposits, where of great thickness and built of land waste, must very often be dominantly terrestrial, especially on the side of the deposit toward the source of supply. This may be seen by reflection on the broader physiographic relations which attend them. If subsidence were the dominating regional feature of the tectonic movement which results in erosion and sedimentation, then there would be a passage to lacustrine or marine conditions. If, however, uplift in the regions of erosion dominates either areally or vertically over subsidence of the regions of deposition, then the basins will be kept filled to the level of the river grade; there will result an excess of sedimentation. The rate of deposition in any section consisting throughout of shallow-water beds is determined not by the rate of erosion, but by the rate of subsidence. The excess of sediment will be carried farther off, the balance being finally deposited in marine formations. But in all except the most arid regions the great carrying agent is river water. Where sedimentation is in excess of subsidence the deposits will consequently bear usually the marks of fluviatile deposition. The conditions of sedimentation can then be divided into two broad classes depending on the ratio of sediment to subsidence. There will only rarely and temporarily occur that delicately balanced condition where subsidence takes place at the same rate, but keeps slightly ahead of deposition, giving rise to permanent yet shallow bodies of water. Nevertheless this balanced state, maintaining a thin yet permanent cover of water, is the one usually assumed to have existed during the Paleozoic when marks of shallow water, of currents, and of exposure to the air are found through great thicknesses of mechanical sediments. It is seen from this analysis that such features must be much more commonly the marks of floodplains and without any necessary relation to shores.

The emphasis of discussion has been placed thus far on the distinctions between fluviatile and lacustrine deposition. There remain to be considered criteria of another category—those which serve to distinguish the fluviatile deposits of seasonally dry and semi-arid climates from the dominantly torrential and wind-borne deposits of true deserts.

In desert mountains there is a maximum of rock exposure. Rock-breaking is due to sun and frost. The unweathered rubbish washes and creeps down the slopes and is broken finer until it is within the reach and greater power of the occasional cloudbursts. These sweep along coarse and fine materials together, but soon lose power, and torrential action, as marked by this heterogeneity, is confined to the perceptibly steep slopes of streams within a few miles of the basin margin.

On the desert basin plains the wind is the chief agent of transportation.

During the long dry periods the sand is shifted by each high wind; the small grains acquire a millet-seed roundness foreign to the work of water; the dust is taken up in the air and exported from the desert basin. Where sand blows across stony floors the pebbles become faceted, giving the sharp-edged and polished forms known as dreikanter. Where sand progressively accumulates through wind action the base of each dune remains behind in the forward marching of the dunes. The dunes of the Sahara are frequently 300 feet in height. Owing to the shifting of winds, all of one series of dunes may be removed elsewhere; a hundred feet of the base of others may remain. Cross-bedding of marked irregularity on a gigantic scale is developed from this in the growing deposit. The cross-bedded members of dune sands are not limited by parallel and horizontal surfaces, and the lines of cross-bedding are broad sweeping curves, tangent to the horizontal at the base and tens or even some hundreds of feet in their radii of curvature.

In true desert deposits there is a marked absence of the argillaceous component, although the sediments of the earth as a whole consist of 80 per cent shale. The constituents of shale are borne from the desert region as dust, deposited hundreds of miles away as loess, or mixed with the deposits of more humid climates, or with the limy oozes of open seas or deep permanent lakes.

Where large rivers maintain their way across deserts or terminate within them the alluvial deposits are very largely reshaped by wind, as over the delta of the Indus, and notable deposits of gypsum and salt mark the sites of lagoons or interior seas.

Contrast the preceding with the conditions of sedimentation under semi-arid or seasonally dry climates. This is an entirely distinct category, yet one which is practically not recognized by Walther, the apostle of deserts. Climates of this character are marked by a concentrated rather than a deficient rainfall. If the temperature of the wet season is not too cold, an abundant vegetation may grow and a rich and varied fauna may inhabit the land. Such climates exist over much of the tropics, as seen in Africa and India; over broad continental interiors in the temperate zones, as seen in the great wheat and cattle lands of the globe.

Under semi-arid climates water is the great transporting agent. During the rainy seasons the shrunken rivers fill again, flow long distances to the sea, sweep gravel far from the hills, wash out the evaporation deposits of the dry season, cover up the mud-cracked alluvial flats with new layers of silt and clay. During the dry season the herbaceous vegetation turns brown, the humus is oxidized out of the soil, the slimes left by the last

flood waters are dried out and cracked, the polygons resulting from the cracking curling up on the edges. From the stream channels sand is blown to leeward and buries, perhaps permanently, the dried and curled plates of mud. The wind plays a much less important part, however, than in true deserts, not so much because of the more restricted period of action as because of the greater efficiency of the water and the binding action of the vegetation of the plains. Clean sands, however, still give rise to dunes, and even in humid climates dune action is not wholly absent.

The significance of limestone deposited in fresh water needs to be considered. It is found to occur under a number of dissimilar conditions.

First, over semi-arid or arid floodplains evaporation of ground water takes place throughout much of the year. The dissolved material which is most abundantly precipitated because of this evaporation is calcium carbonate. Except under truly arid climates, the salt, gypsum, and alkaline carbonates and sulphates are washed out by the following flood waters; but the lime, once precipitated, is relatively insoluble and remains as a cement in the silt and sand. If the waters flow from limestone regions, they are correspondingly richer in lime, and this process may occur in relatively humid climates, as in that over the deltas of the Rhine and Rhone. For the precipitation of lime in floodplain deposits from waters flowing from crystalline rocks, it would appear, however, that the climate must be at least semi-arid in its dryness. In India this cement in the alluvial soils forms impervious nodular layers known as kankar; in Mexico it occurs often as a granular impure limestone, called caliche, and in the western United States such sands and gravels cemented by lime, chiefly at the upper level of the ground water, are known as mortar beds. Probably the agency of plants is inconsequential in this class of lime deposits.

Second, there are found to be deposited in fresh-water lakes and streams lime muds, known as marl, or concretions of nearly pure calcium carbonate. In springs, salt lakes, and in tropic seas deposits of similar composition are also found. In recent years, in fact, it has become recognized that *Chara* mosses, green and blue-green algæ, and bacteria are the agents of calcareous precipitation to such an extent that these lowly vegetable forms are now thought by many to be quantitatively the most important geological agents in the making of limestones. For the deposition of fresh-water limestones, chiefly of algous origin, the only condition appears to be that of some degree of warmth and of richness in calcium bicarbonate. Under the humid climate of the eastern United States such marls have been extensively deposited in the lakes of northern Indiana.[15]

[15] Blatchley and Ashley: The lakes of northern Indiana and their associated marl deposits. Indiana Dept. of Geology and Natural Resources, 25th Ann. Rept., 1901, pp. 31-321.

Recently Roddy has made a careful investigation of the lime concretions discovered by him in streams. He shows that in the streams of southeastern Pennsylvania concretions made chiefly by blue-green algæ grow freely where the amount of calcium bicarbonate in the water reaches 300 parts per million. The growth takes place only during the warmer months of the year.[16]

In humid climates it is, however, only under exceptional conditions that stream or lake waters could attain the content of calcium bicarbonate which would result in a free growth of such fresh-water limestones. Under conditions such as those of the Old Red Sandstone basins, where the waters came mainly from crystalline rocks, for the formation of broad and abundant nodular limestones, the cornstones of the British geologists, a climate of at least semi-arid character would seem a necessary postulate. A truly arid climate is, however, not needed; in fact, the absence of gypsum and salt as associated deposits seems to show that aridity was not present. The physical conditions best adapted for the laying down of the cornstones are those of broad, shallow bodies of warm water, lying in basins beyond the reach of abundant mechanical sediments and largely evaporated during a dry season.

Not until the Cretaceous were grasses evolved, and trees even now can not grow in compact forests on semi-arid lands. So far as present knowledge goes, there does not seem to have been during the Devonian a binding of the soil by vegetation adequate to hold the upland waste of semi-arid climates. If that be true, there would appear to have been at that time but little distinction between the weathering phenomena of truly desert and of semi-arid uplands. No effective soil mantle would have held organic acids, atmospheric carbon dioxide, and moisture within its pores. As soon as the rocks were broken fine enough, the waters of the rainy season would sweep the debris away. Lichens, it is true, would live on the bare rocks, and some bacteria in the regolith. In the wet season these lowly agents would carry on, in a measure, chemical decomposition, but they could hardly be counted as binders of the soil. From these barren uplands there would be a graduation of conditions to the flat parts of river basins. Under a semi-arid climate the level of ground water would not sink far below the surface of these flats. There vegetation could flourish and chemical decay go forward the greater part of the year. Oxidation of the soil would become imperfect; grays and greens as subsoil colors would result. These features are seen to be both qualitatively and quantitatively different from the typical lagoons of desert climates.

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[16] Roddy: Concretions in streams formed by the agency of blue-green algæ and related plants. Proc. Amer. Phil. Soc., vol. liv, 1915, pp. 246-258.

These are the kinds of tests which must be used in the study of the mode of origin of the formations of the Old Red Sandstone.

Description of the Old Red Sandstone Formations

GENERAL RELATIONS

In order that each reader may possess the basis for an independent conclusion on the conditions of origin of a series of formations, detailed descriptions must be given of the significant characters. Since the conditions may shift from stage to stage, these descriptions must cover the whole series with some degree of completeness.[17]

The results of continued investigations by British geologists have shown that the Old Red Sandstone conditions of deposition began in Scotland and in north England in uppermost Silurian times, the marine rocks of the Ludlow passing conformably, by oscillation of conditions, into barren, red and yellow, cross-bedded sandstones, with some conglomerates, and red to gray or green mud-stones. Goodchild states that a violent unconformity separates the base of the true Old Red of Devonian age from these basal rocks, which the British Survey has named Downtonian, but for which Goodchild prefers the name Lanarkian, from their typical exposure in Lanarkshire, in southern Scotland.[18]

Above the Downtonian and unconformable to it comes the Lower Old Red Sandstone, characterized by red and purple sandstones, gray sandy flagstones, and coarse conglomerates. The most characteristic fossils are *Cephalaspis, Pteraspis, Climatius,* and *Pterygotus.* It is typically shown south of latitude 57°, especially in the Caledonian area, according to Geikie, some 20,000 feet of beds being there exposed.

Lower Old Red deposition was closed by disturbances which shifted the regions of great subsidence to the north, especially around the Moray Firth and in Caithness. These are the Orcadian formations, estimated to reach as much as 17,000 feet in thickness. The typical fossils are *Estheria, Dipterus, Osteolepis, Homosteus, Mesacanthus, Coccosteus, Pterichthys,* etcetera.

The Middle Old Red is in turn separated by a profound unconformity from the rocks stratigraphically above, which constitute the Upper Old Red, but recently Flett has shown that the Old Red of the Shetland Islands bridges to some extent this hiatus. The plants of the Shetland

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[17] Descriptions of the features significant of origin will be quoted more fully for the benefit of American readers than if this article were to be printed in a British journal, for the reason that much of the original literature may be difficult of access to many American geologists.

[18] J. G. Goodchild: The older Deutozoic rocks of Great Britain. Geol. Mag., Decade 5, vol. i, 1904, pp. 591-602.

area appear to represent a distinct flora, but the vertebrate fauna shows relationships to the Upper Old Red; consequently it may be the lowest, or one of the lowest, zones of the Upper Old Red. The well determined genera are *Asterolepis* and *Holonema*.[19]

The typical Upper Old Red is found resting with angular unconformity on the Middle Old Red and all older rocks, but passes conformably into the Carboniferous rocks above. The basins of deposition only partly corresponded with those of the older red sandstones. The rocks are characteristically red and yellow sandstones and conglomerates. *Bothriolepis major* and *Holoptychius nobillisimus* are typical species.

From this series of unconformities and shiftings in regions of deposition it is clear that great crust movements were intermittently in progress in this zone during latest Silurian and all of Devonian time. These were accompanied by much igneous activity, since lava flows, breccias, and volcanic ash make up large portions of the sediments, especially of the Lower Old Red. Uplifts along certain axes must have been in progress to have supplied the great quantities of coarse waste. Downsinking of adjacent areas must have accompanied the former in order to permit such thick accumulations. Fault zones and step-faulting are implied; perhaps also true folding. In these ways may be partly explained the remarkable variations in thickness of formations, the disappearance of others, such as the British Survey has recently shown to exist in southern Wales and in northern Devon and Somerset. Here an east-west axis runs through the Bristol Channel. On the northern margin of this axis in Glamorgan the total thickness of the Old Red sandstone is reduced to 400 feet, but on the northern outcrop of this southern Welsh area the thickness swells to 3,000 or 4,000 feet. Similar thicknesses are found in northern Devon, on the south side of this axis. It is not easy to assume a narrow and lofty mountain range between these two basins, enduring without rejuvenescence and gradually buried by the mantle of sediments, for the erosion which would provide this thickness of sediments would also destroy the axial character and height of the mountains. Differential, intermittent uplift of this axis and subsidence of the adjacent belts during sedimentation seems a probable relationship. In the structural complex of ridges and basins we may recognize considerable resemblance between the British Isles in Devonian time and the Cordilleran area of the United States in the Tertiary. The analogy is instructive not only from the structural standpoint, but from the physical conditions of sedimentation as well.

With this introduction on the general character and relationships of

[19] John R. Flett: On the age of the Old Red Sandstone of Shetland. Trans. Roy. Soc. Edinburgh, vol. xlvi, pt. ii, 1908, pp. 313-320.

the Old Red, we may turn attention to those detailed stratigraphic characters which go to show the conditions of origin.

UPPERMOST SILURIAN—DOWNTONIAN FORMATIONS

"*Rocks.*—The series of strata grouped under the term Downtonian has hitherto been regarded as of Lower Old Red Sandstone age, owing to the prevalence of red and yellow sandstones and shales which are the prominent feature of that formation. The recent discovery by the Geological Survey, in shales and mudstones intercalated in these sandstones, of a marine fauna which in some respects is identical with that of the underlying Ludlow Rocks has led to a revision of the classification hitherto adopted. These passage beds are now viewed as forming the highest subdivision of the Upper Silurian rocks. They may be briefly tabulated in descending order as follows:

"Lower Old Red Sandstone, the basal bed being a coarse conglomerate or conglomeratic sandstone, with pebbles composed mainly of greywacke derived from the Southern Uplands.

"Unconformability in the Pentland Hills and in Ayrshire, apparent conformability in Lanarkshire.

Downtonian.	4. Chocolate-colored sandstone.
	3. Conglomerate with quartzite pebbles derived from the Highlands.
	2. Green and red mudstones with bands of greywacke and brown flaggy carbonaceous shales with fishes and eurypterids.
	1. Red and yellow sandstones and mudstones, underlain in the Hagshaw Hills by a fine conglomerate of local occurrence, resting conformably on Upper Ludlow Rocks.

"*Fossils.*—The organic remains, which are restricted to Zone 2 of the foregoing series of strata, consist of plants, ostracods, phyllocarid crustaceans, eurypterids, and fishes.

"Among the fragments of plants obtained from this horizon, Mr. Kidston has identified *Pachytheca* and one specimen as belonging to the genus *Parka*, though of a different species from *P. decipiens.* The ostracods are represented by Beyrichia, a form which is common in the Upper Silurian rocks of the Southern Uplands; the phyllocarid crustaceans by *Ceratiocaris.* Most of the genera of eurypterids found in the Wenlock and Ludlow Rocks in Lanarkshire and the Pentland Hills, viz.: *Eurypterus*, *Pterygotus*, *Slimonia*, *Stylonurus*, have been obtained from the Downtonian fish-band (Zone 2 of above table).

"The most striking palæontological feature, however, is the remarkable assemblage of fishes procured from this horizon which are wonderfully complete when carefully extracted from the carbonaceous shales. Dr. Traquair has identified in the collection of the Geological Survey five genera of fishes, four of which are new, and seven new species. One genus (*Thelodus*) is common to the Upper Ludlow Rocks of Lanarkshire and Wales and to the Lower Old Red Sandstone of Forfarshire and Oban.

"*Conditions of deposition.*—The Downtonian strata indicate a marked change in the phases of sedimentation from those which obtained in Ludlow and Wenlock time in the south of Scotland. While it is true that the green mudstones,

greywackes, and brown carbonaceous shales yielding fossils resemble lithologically Upper Silurian rocks, still the dominant feature of the series as a whole is red and yellow false-bedded sandstones. It seems just to infer that the Downtonian fish-band and the associated mudstones and greywackes are marine deposits, for some of the eurypterids found in the latter strata are the associates of graptolites in the Wenlock Rocks of the Pentland Hills, and of brachiopods (*Lingula minima*) in the Ludlow Rocks of Lanarkshire. Moreover, the occurrence of the Polyzoon, *Glauconome*, together with *Spirorbis* and sponges, likewise points to the marine origin of some of the Downtonian strata. The red and yellow false-bedded sandstones, on the other hand, evidently herald those conditions which prevailed during Old Red Sandstone time, when the open sea gave place to brackish water or inland lakes." [20]

Peach and Horne call this fauna marine, but there is to be noted the absence of cœlenterates, brachiopods, echinoderms, and trilobites, representatives of which are found in the true marine Ludlow rocks. This absence is as striking as the lingering presence of a few marine types. On the other hand, the ostracods, eurypterids, and fishes are groups which are found also as characteristic fossils in clearly fresh-water deposits as well as in brackish water or marine deposits. The conditions of deposition of the fossiliferous zone would seem therefore to represent the recurring but temporary existence of brackish water, permitting for a time the incursion of a fauna related more to the open sea than to the land. It seems to have been but a temporary condition, since the other formations, as noted by Peach and Horne, are suggestive of the true Old Red Sandstone conditions. The descriptions suggest the current-laid sediments of streams rather than a condition of lakes or bays.

Two hundred miles south, in Staffordshire, limited outcrops of uppermost Silurian rocks have been recently discovered which show brachiopod faunas.[21] One hundred miles northeast of Lanarkshire the Downtonian rocks outcrop again along the shore at Stonehaven beneath the true Lower Old Red. Hickling gives these basal Stonehaven beds a thickness of 1,500 feet and notes the occurrence at the base of breccia, followed by fine red sandstone, with numerous thin bands of bright red shale. Higher up several beds of the red marly shale, 50 to 100 feet in thickness, are intercalated with light red or yellow sandstones and fine grits with some bands of gray sandstone and grit. The series of beds is distinctly fine in character as compared with the overlying mass of the Old Red.[22] The base at this place is regarded by R. Campbell as an unconformity and not a

[20] Peach and Horne: The Silurian rocks of Britain. Mem. of the Geol. Survey of the United Kingdom, vol. i, Scotland, 1899, pp. 67-69.

[21] W. W. King and W. J. Lewis: The uppermost Silurian and Old Red Sandstone of South Staffordshire. Geol. Mag., Decade 5, vol. ix, 1912, pp. 437-443.

[22] The Old Red Sandstone of Forfarshire, Upper and Lower. Geol. Mag., Decade 5, vol. v, 1908, p. 399.

fault zone. The thickness is given as nearly 3,000 feet, and from a thick belt of gray and greenish mudstones and shales fossils have been obtained—phyllocarids, myriopods, eurypterids, fragments of scorpions, plant fragments, and worm tracks. Further, a thin bed of reddish mudstone underlying the above series has yielded numerous plates of a new Cyathaspis.[23] Of these fossils the phyllocarids, as an order, are typically marine; the myriopods and scorpions are as typically terrestrial. The phyllocarids belong, however, to the class of crustaceans which has always exhibited a freedom of adaptation to changes of salinity, possibly greater than is found in any other group of organisms.

From these descriptions of uppermost Silurian rocks and their fossils, judged in the light of more intensive studies of other delta deposits, it would seem that toward the close of this period delta conditions had developed from the northwest, pushing the littoral zone south of Scotland. The Scottish deposits were dominantly subaerial, forming in the main fluviatile delta deposits in Downtonian times. Occasionally, as is found on the fronts of all large deltas of low gradient, submergence would bring in wide shallow bays of brackish waters with such groups of animals as were least sensitive to changes of salinity. At rare intervals this faunal invasion reached as far inland as southern or central Scotland. The climate was dry enough to permit drying out and oxidation of the deposits of the floodplains, but there is nothing in the chemical compositions or sedimentary structures to imply the existence of a desert climate.

The evidence is not so determinative as could be wished, partly no doubt because it has not been searched bed by bed for the structural features, partly because evidence which may in another decade be regarded as determinative is not generally regarded as such at the present time.

LOWER DEVONIAN—LOWER OLD RED

In Cornwall and southern Devon all, or nearly all, of the Lower, as in fact the rest here of the Devonian also, is marine. In southern Ireland, however, the beds are largely or entirely fresh water in origin, since no marine fossils have ever been found there.

In south Wales the Lower Old Red is represented by the cornstone series. This consists below of red marls with bands of nodular limestones (cornstones) and irregular beds of red micaceous sandstones. Above are the Senni beds, consisting of green and dull red sandstones with marls and cornstone conglomerates.

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[23] The Downtonian and Old Red Sandstone of Kincardineshire. Geol. Mag., Decade 5, vol. ix, 1912, p. 511.

"In this cornstone series cornstones occur sometimes as continuous beds of pale red or green compact limestone, and sometimes as nodular concretions in the marls; they consist entirely of amorphous carbonate of lime enclosing some sand, and no fragments of organisms except obscure plant remains can be seen in them. They may owe their existence to the agency of some lime-secreting algæ, like that which forms the 'sprudelstein' of Carlsbad (described by F. Cohn in 1862) and the travertine of the Mammoth Hot Springs in the Yellowstone Park, U. S.

"The Cornstone series has yielded fish of the genera *Pteraspis* and *Cephalaspis*, and there can be no doubt that it is homotaxially the equivalent of the marine Lower Devonian and of the Lower Old Red Sandstone of Scotland. The Senni Beds are included in this series, because they also contain *Pteraspis;* they only occur in that part of the area which lies to the west of Brecknock, where they have a maximum thickness of 1,200 feet. . . .

"When the formation is followed westward beyond Llandeilo several changes are found to take place. The base of the Cornstone series ceases to show an upward passage from the Tilestones, the basement beds becoming first sandy and then conglomeratic, at the same time gradually passing across the passage beds and the Ludlow mudstone till, near Carmarthen, they have overstepped the whole Silurian series and rest directly on the Bala Beds. The whole group also becomes thinner, and is not more than 2,500 feet near Llandarog." [24]

These Welsh deposits have been regarded by British geologists as fresh water in origin and formed in a large lake. Much of the formations may, however, equally well, if not better, be regarded as fluviatile. The great thickness, taken with the arenaceous character, indicates shallow-water conditions maintained by subsidence. It would be difficult to conceive of a continuous fresh-water lake existing throughout and excluding the sea which lay not far to the south of the narrow intervening axis of elevation. If, however, sedimentation were, on the whole, faster than subsidence, fluviatile plains would result and the sea could be readily excluded, at the same time that intermittent lacustrine conditions could exist. Further, although the limestones, where pure and thick, suggest such lacustrine conditions, nodular layers of earthy limestones do not require such an origin. It may be concluded, therefore, that in the Welsh basin the deposits suggest combinations of fluviatile and lacustrine conditions. The large difference which this means in interpretation is that much of the sediment was deposited on river floodplains, and on paleogeographical maps the area should not be represented as a great lake basin, but as land instead of water.

Turning to the Caledonian basin, this, under the interpretation of Jukes-Browne, may be taken as including all that broad region south of latitude 57° and north of 54°. The chief area is that of southern Scotland, but small outlying remnants occur in both Scotland and northern

[24] Jukes-Browne: The building of the British Isles, 1911, pp. 108, 109.

Ireland. The best continuous exposure is that shown on the southeast coast of Scotland from Stonehaven to the Firth of Tay. A detailed description of these rocks is given by Hickling, and the following is quoted from him, omitting that of the Stonehaven beds, which are now regarded as Downtonian in age.

"*Table of the Lower Old Red of Forfarshire*

	Feet
Edzell Shales	? 1,000
Arbroath Sandstone	1,200
Auchmithie Conglomerate	800
Red Head Series	1,500
Cairnconnan Series	2,000
Carmyllie Series	1,000
Dunnottar Conglomerate	5,000
Stonehaven Beds	1,500
	14,000

"It must be remarked that the subdivisions in the above table are based purely on lithological characters and are only made for convenience of description. No breaks in the series exist to my knowledge, and I am far from supposing that these subdivisions are likely to be traceable for any great distance; rapid lateral variation in the character of the rocks is too obvious a feature of the Old Red Sandstone. The names applied to the subdivisions are taken from the localities where the series may be typically seen. The thickness of the subdivisions are estimated from theoretical sections for the most part, and are therefore to be regarded as only approximately accurate. . . .

"*The Dunnottar Group* of coarse red and grey sandstones, grits, and conglomerates which form the bold coast the whole way from Stonehaven to Johnshaven. As I have only been able to examine the base and the top of this series, I shall add no more than that it forms by far the most extensive series of conspicuously coarse deposits in the district. In its conglomerates pebbles commonly range up to a foot or more in length, and yet are astonishingly well rounded. They mostly consist of quartzite. South of Johnshaven several thin lavas are interbedded with the top of this series, with sandstones and coarse conglomerates of porphyrite blocks between. Beyond this the coast-section is interrupted by the mass of Upper Old Red which is faulted in, extending from East Mathers to Milton Ness (described below), and which covers the junction between the conglomerate series and the great mass of lavas which forms its natural top. These lavas occupy the coast southward by Montrose to Lunan Bay, being hidden, however, almost the whole way to Montrose by sand and alluvium. From Lunan Bay their outcrop strikes inland along the summit of the anticline by Friockheim and Letham, near which latter place they finally die out. About Friockheim and Leysmill are numerous quarry sections of the

"*Carmyllie Series*, which overlies the lavas. Compact red or grey sandstone is the predominant rock of this series, with subsidiary masses of grey flagstone and blue or red shale, termed 'caulm' by the quarrymen. Together with their

interbedded lavas, these rocks form the whole axis of the Sidlaws, all along which they are quarried for building and paving material. The well-known Carmyllie quarries are in the middle of this series. Passing upward, the

"*Cairnconnan Series* is reached, distinguished by its coarser materials, principally dull red or grey grit with bands of conglomerate. The conglomerates are more particularly developed on the north side of the anticline, as at Turin Hill, north of Rescobie Loch. This series should appear on the coast in Lunan Bay, but it is entirely hidden by the sand and alluvium. At the south end of the bay another series of lavas, admirably exposed for study, intervenes between it and the

"*Red Head Series*, which forms the bold cliffs from the promontory of that name southward to Rumness. In its lower part it consists of fine red thin-bedded sandstone with bands of hard bright red shale, while the upper portion is made up of thicker-bedded sandstone. Some six or seven miles to the southwest, at Arbirlot, the lower part of this series, as seen in the banks of the Elliott Burn, consists mainly of blue and grey shales, with partings of sandstone, having so strong a resemblance to some of the rocks of Carmyllie as to have led Hugh Miller to consider them as a repetition of that series. This case illustrates very well the rapid lateral variation to which all the beds of the Old Red Sandstone are liable.

"*The Auchmithie Conglomerate* overlies the previous group in the cliffs just north of the village so named. The series consists of three main masses of conglomerate, with intervening sandstones and conglomerates. The pebbles in the conglomerates are well rounded, fairly large (generally 1 to 6 inches, rarely 12 inches), and, as usual, are mostly quartzite. The thickness of this conglomerate series diminishes along its outcrop to the southwest.

"*The Arbroath Sandstone* is the highest series of the Lower Old Red seen on the Forfarshire coast. Coarse, gritty, sometimes pebbly sandstone is its component rock, always red in color. Just above the base of the series, by the Signal Tower at Arbroath Harbor, there is a single band of grey grit and marlstone on the shore, containing nodules of limestone from the size of a pea to 1 foot in diameter. This is noteworthy in view of the almost complete absence of lime from the Lower Old Red System. . . .

"*The Edzell Shales* . . . overlie the Arbroath sandstones. They are generally bright red fine sandstones, shales, and marls, either hard or soft, frequently mottled with small circular patches of pale yellow, grey, or green, or more rarely with bands of the same color. . . .

"The volcanic rocks of the district do not call for description here. It may suffice to remark that they are, with very rare exceptions, in the form of contemporaneous interbedded sheets, and are merely a continuation of the series of the Ochil Hills, where they have been described in detail by Geikie and others (A. Geikie, 1900).

"Attention must now be drawn to a point, the importance of which has not, I believe, been hitherto recognized. All the recorded fossils from this district—and I suspect that the same applies to Perthshire—are from a very limited series of horizons near the middle of the Lower Old Red System, the Upper Old Red being, of course, left out of account. The Carmyllie series is the fossiliferous group *par excellence*, while a few of the worked localities may lie in the Cairnconnan series (*e. g.*, Tilliewhamland quarry, Turin Hill),

or the top of the Dunnottar conglomerates. Odd fossils have occasionally been obtained from other horizons, but they are quite a negligible quantity." [25]

To the west, the sections as exhibited in Fife and Kinross show enormous quantities of agglomerates, lavas, and tuffs. More or less rude sorting of the breccias shows some rearrangement by water. Some beds of breccia betray, however, no stratification; others, on the contrary, show a great deal of rounding and sorting of pebbles and boulders. A. Geikie states that the series of deposits in the Caledonian basin everywhere presents traces of shallow-water conditions.[26] He seeks to interpret the whole as laid down in an open lake and sorted by wave action. He notes that—

"An objection may arise that the remarkable coarseness of the conglomerates, and the large size of many of their included bowlders, are suggestive rather of the powerful breakers of the open sea than of the limited wave-action of a lake or inland sea. But possibly the coarseness of the shingle may rather be some indication of the dimensions of the lake and of the power of the waves along its exposed shores." [27]

It seems, however, that a reinterpretation is called for. The widely extended and coarse conglomerates do not suggest shore action, but resemble the stream-borne detritus of Rocky Mountain valleys. Their coarseness, thickness, and distance of transportation are all significant of stream rather than wave action. The red or gray sandstones and red shales are similar to the Catskill deposits of New York and Pennsylvania, and are such as in India and North America have become commonly regarded as fluviatile in origin.

MIDDLE OLD RED—ORCADIAN FORMATIONS

Relations to older rocks.—During the middle part of the Old Red Sandstone period the chief axes of subsidence and deposition were transferred to the northern part of Scotland. Its locus has become known as the Orcadian Lake, or, better, the Orcadian basin. Disturbance and some erosion of the Lower Old Red may have resulted in retransfer of material. The enormous thicknesses of deposits imply vigorous crust movements and profound erosion. The fossiliferous beds show that the Middle Old Red is younger than the Lower Old Red to the south, but there is no doubt but that the Caledonian deposits once extended northwest of the

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[25] The Old Red Sandstone of Forfarshire, Upper and Lower. Geol. Mag., Decade 5, vol. v, 1908, pp. 398-401.

[26] Text-book of geology, 1903, p. 1008.

[27] Geology of East Fife. Mem. of the Geol. Survey, Scotland, 1902, p. 43.

present fault boundaries; so that Lower Orcadian beds may correspond to Upper Caledonian.

The basal beds are preserved in certain small areas in Aberdeen and Banff. These show in some cases clearly the form of old filled river valleys. A. Geikie describes that which is now dissected by the River Avon, latitude 57° 20′ north, longitude 3° 20′ west.

> "A marked structure in some parts of the conglomerate is a kind of false-bedding of the stones. Between the gently inclined lines which mark the true dip, the stones of each bed of conglomerate are arranged in a rude stratification obliquely across the line of the valley at angles of 17° to 20°. They thus appear to dip toward the hills (representing the old valley walls), while the true inclination of the conglomerate beds is away from them." [28]

This is a highly significant feature. It seems clearly to represent the stream-shingling of gravels, by which the longer axes of the pebbles slope upstream. The situation and character does not suggest beach sorting.

Old Red of the Moray Firth.—Passing to the old Red Sandstones around the Moray Firth, Geikie states:

> "We have found them throughout that extended tract mainly conglomeratic and arenaceous—the conglomerates in thick masses coming in again and again on successive platforms, while interstratified with them lie bands of grey clay and shale full of calcareous nodules containing fish remains. These fossiliferous bands retain their distinctive characters, lithological and palæontographical, throughout the whole district" (page 446).

These strata stand in great contrast to the vast continuous flagstone series of Caithness to the north, though they are considered by Geikie to be equivalent to the upper portion of the Caithness section.

Formations of the Orcadie basin in Caithness.—A tabulation of the formations which comprise the whole terrane, with an abstract of such features as bear most strongly on the problem of origin, is based on Geikie's complete report in the Transactions of the Royal Society of Edinburgh.[29]

Nearly the whole of Caithness consists of Old Red Sandstone. The interior is almost entirely covered with peat and glacial drift, but the powerful action of the ocean on these rather friable rocks has exposed admirable sections often several hundred feet in height around the entire coastline. These have been compiled by Geikie into a type section of the whole series.

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[28] A. Geikie: On the Old Red Sandstone of western Europe. Trans. Roy. Soc. of Edinburgh, vol. xxviii, pt. ii, 1878, p. 427.

[29] Vol. xxxviii, pt. ii, 1877-1878, pp. 355-421.

Subdivisions of the Lower Old Red Sandstone of Caithness

	Feet
9. John o'Groat's Sandstone and Flagstone Group	2,000
8. Huna Flagstone Group	1,000
7. Gill's Bay Red Sandstones	400
6. Thurso, or Northern Flagstone Group	5,000
5. Wick, or Eastern Flagstone Group	5,000
4. Langwell and Morven Sandstones and Conglomerates	2,000
3. Badbea Breccia and Conglomerate	300
2. Braemore and Ousedale Sandstones	450
1. Basement Conglomerate	50
	16,200

The significant details of these formations are as follows:

1. *Coarse Basement Conglomerate*.................................. 50 feet

This was laid down on an uneven floor of igneous and metamorphic rock. It presents a remarkable granitoid aspect to such an extent that it is often not easy to determine where the conglomerate ends and the granite begins. Its component blocks vary in size up to as much as a yard, or even more, in length. The bowlders are for the most part tolerably well rounded. The thickness given was measured at the place where studied, but the basement conglomerate over the basin as a whole must vary much both in thickness and in age.

2. *Braemore and Ousedale Sandstones*............................ 450 feet

These are dull chocolate-red sandstones with sandy shales or clays. It is noteworthy how abundantly pink orthoclase occurs in the matrix of many of the sandstones. The red shales and sandstones of Braemore are sometimes pitted as if by rainprints, but have as yet yielded no fossils.

3. *Badbea Breccia and Conglomerate*............................ 300 feet

By far the most conspicuous member of the Old Red Sandstone series in the south of Caithness is a remarkable breccia or brecciated conglomerate. It occurs in thick beds, wherein little or no trace of stratification may be found. The stones, considerably smaller than in the basement conglomerate of Braemore, seldom exceed five or six inches in length. They consist mainly of pink cleavable orthoclase, pink granite, grey quartz-rock, white vein-quartz, and occasional pieces of red sandstone. The feldspar is the predominant ingredient, and likewise enters largely, in a comminuted state, into the composition of the paste (pages 378-379).

4. *Langwell and Morven Sandstones and Conglomerates*........... 2,000 feet

The Badbea breccias and conglomerate "pass up into a thick series of dull chocolate-red, grey, and yellow sandstones, with layers of dull-red and olive-colored shales and of fine conglomerate. . . . In their lower part they are highly felspathic, with a rather coarse texture, and many scattered pebbles, as well as nests and bands of conglomerate. Higher up they are more flaggy, and they finally pass upward imperceptibly into the dull-red and grey flagstones of Berriedale. Nothing but an arbitrary line can be drawn for their upper limit. . . . The group has as yet yielded no fossils" (pages 379-380).

Tracing these beds toward the north they are found to lose the coarse pebbly and conglomeratic features and to pass into fine flaggy sandstones, with sandy shales, the whole having a prevailing dull chocolate-red tint, through which seams of greenish-gray shales and flagstones occur. In places, as observed by Sedgwick and Murchison, the red tint is local and even superficial, the same stratum being red or green at different parts of its course. Traced inland to the west the beds so increase in the quantity of coarse detritus that on the north side of the Scarabin ridge hundreds of feet may either be called highly conglomeratic sandstones or sandy conglomerates.

"The four groups of strata, above described, may be regarded as forming together a red sandy and conglomeratic base, of very variable thickness, on which lies the great flagstone series of Caithness now to be discussed" (page 386).

5. *Wick, or Eastern Flagstone Group*............................ 5,000 feet

This group consists of dark-gray flagstones which are often thick-bedded, thin shales and limestone bands; the whole passing down into red shales and sandstones.

The group is distinguished from that which overlies it by the greater massiveness of its flagstones, and by their less calcareous composition and less fissile or shaly texture.

Sun-cracks and ripple-marks abound and in various horizons remains of terrestrial plants have been found, one gray shale in particular having its surface covered with carbonized vegetation. Large stems belonging to tree ferns and gymnosperms also occur. An abundant fish fauna has been obtained from this formation.

6. *Thurso, or Northern Flagstone Group*........................ 5,000 feet

Dark-gray and cream-colored flagstones, gray and blue shales and thin limestone; some beds strongly bituminous. This group is more fissile, shaly, and calcareous than the preceding. "The flagstones which, towards the east, retain the usual normal characters of fissile calcareous strata, pass into sandstones and conglomerates as they approach and rest upon the granite and gneiss" (page 391).

"The next feature to engage the attention of the observer is probably the extraordinary abundance of ripple-marked surfaces and sun-cracks. Though these markings abound also in the lower flagstone group, it is here that they attain their greatest development" (page 392).

"More abundant and admirable illustrations of sun-cracks could hardly be found than occur along this coast. Broad gently-inclined sheets of rock again and again present themselves to view so covered with reticulations as to look like tesselated pavements. It may be noticed that the cracks not infrequently descend through many of the fine laminæ of deposit for a depth of five or six inches with occasionally a breadth of three or four inches. The material filling up the interstices abounds with small, occasionally curved pieces of shale. These may, no doubt, be regarded as portions of the upper muddy layer which cracked off and curled up during desiccation, as may often be observed on dried-up pools at the present time. Some pittings, occasionally seen on the sun-cracked surfaces, may perhaps represent rain-drops. Altogether, no evidence could more conclusively indicate a long-continued, tranquil deposit of

fine sediment in shallow water, which frequently retired and left wide tracts of muddy shore to be dried and cracked by exposure to the sun" (page 393).

The resemblance which the fissile calcareous flagstones "bear to some of the so-called fresh-water limestones and cement-stones at the base of the carboniferous system of the south of Scotland, cannot but strike any one who is familiar with the latter strata. This likeness includes not only the composition, color, and mode of weathering, but even the minute wavy lamination indicative of intermittent but tranquil deposit. Other shaly layers are strongly pyritous" (page 400) . . . "organic remains abound in the strata exposed on the shore between Dunnet Bay and Reay. Fragments of fish and coprolites are scattered abundantly through most of the flagstones. Some of the calcareous shales are full of *Estheria*, while traces of plants occur in great numbers, though generally in a somewhat macerated condition" (page 393).

The groups to which the plants belong are Ferns, Calamites, Lepidodendrids, Stigmaria, and Araucarioxylon. No traces of marine plants have been found.

7. *Gill's Bay Red Sandstone* .... 400 feet

This formation consists of red, friable, false-bedded sandstones, both its base and top interleaved with seams of flagstone and grading into the flagstone groups. No fossils have yet been found in these sandstones.

8. *Huna Flagstones* .... 1,000 feet

To the alternation of red sandstone and flagstones succeeds the Huna flagstone group having characters similar to those of the Thurso flagstones.

9. *John o'Groat's Red Sandstones and Flagstones* .... 2,000 feet

These consist of a mass of false-bedded red sandstones, with intercalations of flagstones, the whole much resembling the Gill's Bay formation. The sandstones "occur in successive thicker zones, between which lie many alternations of red sandstone, red and blue flagstones, grey shale, and impure limestone. These latter strata are quite undistinguishable from portions of the older flagstone groups. The highest part of the group consists of a thick mass of false-bedded red sandstone, without flagstone or shale. Fossils occur in some of the blue flagstones and impure limestones" (page 404).

Old Red Sandstone of the Orkney Islands.—The greater part of the section previously given is traceable into sandy and conglomeratic facies contiguous to the old margins of the basins. It is important, therefore, in any view of the Orcadie basin as a whole to compare the preceding with the stratigraphic characters as observed throughout the Orkney Islands, since these were much farther from the limits of the basin.

In the same report from Geikie from which the preceding statements have been abstracted is given also an account of the stratigraphy as observed in the Orkney Islands.

"Almost the whole of the Orkney islands consist of flagstone and sandstones of the Caithness flag series. The only other formations present appear in the southwestern part of this group. A small ridge of the underlying crystalline rocks rises to the surface at Stromness" (page 408).

"The flagstones retain the same features so well marked in Caithness. Sometimes, as at Skaill in Pomona, they are exceedingly hard, fissile, bituminous, and crowded with fossil fish. In other places, as near Kirkwall, they form thicker beds, and can be quarried for building materials, like those which are similarly used at Thurso. Bands of dull red and even yellowish sandstone occur interstratified with the flagstones, as in Scapa Bay, Meal near Kirkwall, Eday, and other places. Where the flagstones rest on the old crystalline rocks they become for a short space conglomeratic at the base" (page 409).

At certain localities occur zones of red sandstone which may be paralleled with the John o'Groat's and Gill's Bay groups of the Scottish mainland. As we advance northwards among the islands the same petrographical characters continue. One "seems to be forever meeting with repetitions of the same rocks. No doubt when these islands come to be mapped in detail, the real thickness of flagstones will be found to be more considerable than might at first have been surmised." The Orkney rocks appear to belong to the upper groups of the Caithness section, since "no equivalents are met with of the massive red sandstones, shales, and conglomerate groups at the base of the Caithness series." "The coarse conglomerate of well-rounded sandstone blocks at Heglabir on the west side of Sanday, which has been long known (see Barry's "Orkney," page 56, and Neill's "Tour"), seems to occur at a greater distance from the local base, for it is said to overlie sandstones and flagstones" (page 410).

"Many of the flagstones of Orkney are charged with organic remains. Especially is this the case with some of the dark, hard, fissile, bituminous bands. On the surfaces of these strata remains of the characteristic ichthyolites are crowded thickly together, and usually in such a tolerable state of preservation as to show that the fishes must have died where their remains are found, or at least that they could not have been subjected to any prolonged exposure and transport before they were buried under the accumulating sediment. As a rule, the fossils have been converted into a brittle jet-like substance, which is so liable to crack and scale off, that unless great precautions are taken, an organism, which at first showed external sculpture in great beauty, becomes eventually a mere black bituminous patch, retaining only the outline of the original specimen. It is not difficult, in most cases, to distinguish an Orkney from a Caithness ichthyolite.

"The fossil plants of Orkney include most of the forms found in the Thurso and upper Caithness groups" (page 411).

Interpretation of the Orcadian deposits.—The structural features of the strata which are significant of origin have been given by Geikie in more detail than is found in other descriptions. They permit, therefore, of a more specific interpretation.

Significance of conglomerates.—It has been shown that subaerial conglomerates may be laid down at much greater distances from the sources of supply than subaqueous conglomerates, since streams may transport resistant gravel until they lose velocity or become loaded with finer material. Subaerial conglomerates may also accumulate with much greater thicknesses than subaqueous conglomerates. The only conditions

necessary for the continuance of deposition of subaerial conglomerates is the maintenance of rapid erosion to supply the material and river volume and grade sufficient for its transportation. The conditions for the continuance of deposition of subaqueous conglomerates, on the contrary, depends on the permanent existence of a shore of suitable materials and a depth of water just such that waves and currents may transport gravel. The great Pleistocene gravel deposits of the continental interiors testify to the magnitude of the first class of conglomerates, while the limited distance to which present gravels are transported from shores, as shown by hydrographic charts, indicates the relative insignificance of the second.

The pebbly sandstones far from the base of the Caithness section and at distances of many miles from the regions of erosion are highly suggestive of subaerial conditions, while conglomerates, such as those of the Moray Firth, forming thick masses, coming in again and again, and overlying formations of clay and shale, may be taken as fairly conclusive evidence of terrestrial deposition.

Significance of colors.—Variegated colors, especially where these alter from one stratum to another and even within a single stratum, are highly characteristic of continental deposits, as Walther has pointed out. Red sediments have been deposited to a limited extent under permanent water bodies, either salt or fresh, but are characteristically of terrestrial origin. Even where deposited under a water body the color is due to previous thorough oxidation of the iron while exposed to the air without the usual opportunity for later subaqueous deoxidation.

The climatic conditions which may give rise to red tones in consolidated deposits are rather broad. As argued elsewhere,[30] the presence of red merely implies the existence at the time of deposition of either temperate or torrid climate with a dry season sufficiently marked to permit periodic aeration of the floodplain soil.

The dominantly red color and variegated character of the conglomerates and sandstones is therefore strongly suggestive, though not conclusive in itself, of terrestrial origin under rather broadly limited climatic conditions.

The presence of the dominantly gray and blue colors in the flagstone groups with their high content of bitumen implies that, if of terrestrial origin, they were deposited under conditions which did not permit sufficient aeration and oxidation to eliminate the organic matter and oxidize the iron. Such conditions are broadly developed over the lands in the lowest portions of river floodplains, more or less continuously in a swamp condition, more especially in climates without marked dry seasons, or in

[30] Joseph Barrell: Jour. Geol., vol. xvi, 1908, pp. 285-294.

shallow lakes which are dried out only at occasional times. Such flood-plain or playa lakes may exist readily under climates with marked dry seasons, but shift in area broadly under such conditions and leave wide mud-cracked zones.

The writer has elsewhere compared the stratigraphic characters of the Orcadie basin to those of the Seistan basin in eastern Persia.[31]

Significance of mud-cracks and rain-prints.—The Wick and Thurso flagstone groups, possessing a total thickness of some 10,000 feet, comprise the middle two-thirds of the Caithness section. One of the most striking features noted by Geikie is the presence throughout of mud-cracks. He also mentions that the red shales and sandstones of Braemore are sometimes pitted as if by raindrops. It has been stated further that the flagstone groups exhibit the same lithologic characters in the Orkney and Shetland islands.

Reasons have been given in full elsewhere for holding that mud-cracks occurring regularly through argillaceous strata of great depth and horizontal extension can only be produced by fluviatile deposition over broad floodplains under climates with periodic rainfall, or in the central playa basins toward which such rivers drain.[32] The alternating sandy and shaly character of the strata of these mud-cracked formations finds also in this view a natural explanation.

It has been noted further that on passing downward toward the base of the system, or on the same stratum toward the margins of the basin, the yellowish, grayish, or greenish flagstone shale strata pass into reddish and arenaceous beds. Since the flagstone portions are interpreted to belong to the lower portions of the floodplains, the reddish arenaceous beds into which they pass laterally must be from their position also terrestrial and more nearly marginal to the basin. The explanation of the contrast in color is that, from being deposited on the better-drained borders of the basin and possessing naturally a more porous nature, oxidation of the beds during deposition has taken place more freely.

Significance of intercalated limestones.—Especially in the flagstone groups, but also to some extent in the other groups, the presence of highly calcareous shales was noted, with occasional strata of thin-bedded impure limestones. Such fresh-water calcareous deposits originate on the bottoms of lakes protected to some extent from the inwash of sediment and are especially apt to occur where evaporation is considerable. Such water bodies, of a temporary and shifting nature, are a usual accompaniment of fluviatile aggradation in broad basins or over terminal deltas, due to

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[31] Bull. Geol. Soc. Am., vol. 23, 1912, pp. 418, 419.
[32] Journal of Geology, vol. xvi, 1906, pp. 524-568.

the flatness of the surface and unequal upbuilding. Over the delta of the Nile, for instance, similar deposits are at present forming. Examples of somewhat more permanent lakes due to the damming of a main drainage axis by tributary fans may be cited in Tulare Lake, in the Great Valley of California, or Lake Wulur, in the Vale of Cashmere.

Calcium carbonate deposits, as previously noted, originate also over the surface of floodplains in arid or subarid climates by continued evaporation of subsurface waters without the presence of any permanent superficial water body. The calcareous sandstones found in these Devonian deposits are suggestive of such relations, but the presence of limestones of considerable extent and some degree of purity, associated particularly with the gray flags and sometimes holding fish fossils, seem to show, however, that the purer limestone strata were laid down in shallow temporary lakes, rather than developed by evaporation under arid conditions over the periodically desiccated floodplain.

LOWEST UPPER OLD RED OF THE SHETLAND ISLANDS

The lowest horizon of the Upper Old Red occurs in the Shetland Islands, and the rocks are described as follows by Flett:

"A little west of Lerwick, coarse conglomerates are faulted against the metamorphic series. They dip towards the east, and are succeeded at the town of Lerwick by reddish and grey sandstones, often current-bedded, and sometimes containing large rounded pebbles of quartzite, granite, etc. At the point southeast of Lerwick known as the Nabb, grey micaceous sandstones occur, full of plant-remains, and containing also the small crustacean *Estheria membranacea*. On the opposite shore of Bressay Island the first beds met with are brownish and grey sandstones, often conglomeratic, and sometimes brecciform, with occasional grey and reddish shales. . . . In crossing Bressay the dip of the rocks is consistently east or southeast, varying from ten to thirty degrees. The commonest rocks are grey, micaceous, thin-bedded sandstones, with coarser, less micaceous, gritty seams, often current-bedded. The sandstones contain rounded clay galls, and their surfaces are often covered with blackened fragments of plants and shreds of fine shale. . . .

"In view of the persistent easterly dip, often at fairly high angles, the whole thickness of this series must be several thousand feet; but the evidence of faulting along the shores of the Sounds is sufficient to render exact estimates impossible. The fish beds in Cullinsburgh Voe are rather above the middle of the Bressay Sandstones. The fossils occur in a thin-bedded, flaggy, grey micaceous sandstone, and the plates are black in color and well preserved. With them thin black impressions of plants are exceedingly common. The strata were evidently laid down in shallow water, close to land; and the general facies of the rocks and of the fauna is in harmony with the supposition that they were fresh-water deposits." [33]

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[33] Flett: On the age of the Old Red Sandstone of Shetland. Trans. Roy. Soc. Edinburgh, vol. xlvi, pt. ii, 1908, pp. 315, 316.

THE UPPER OLD RED SANDSTONES

Of these rocks in Scotland and England, A. Geikie makes the following statements:

"This division consists of red sandstones, deep-red clays or marls, conglomerates, and breccias, the sandstones passing into yellow or even white. These strata, wherever their stratigraphical relations can be distinctly traced, lie unconformably upon every formation older than themselves, including the Lower Old Red Sandstone, while, on the other hand, they pass up conformably into the Carboniferous rocks above. As already remarked, they were deposited in basins, which only partially correspond with those wherein the Lower Old Red Sandstone had been laid down. Studied from the side of the underlying formations, they seem naturally to form part of the Old Red Sandstone, since they agree with it in general lithological character, and also in containing some distinctively Old Red Sandstone genera of fishes, such as *Bothriolepis*, *Coccosteus*, and *Holoptychius;* though, approached from the upper or Carboniferous direction, they might rather be assumed as the natural sandy base of that system into which they insensibly graduate. On the whole, they are remarkably barren of organic remains, though in some localities (Dura Den in Fife, Lauderdale) they have yielded a number of genera and species of fishes, crowded profusely through the sandstone, as if the individuals had been suddenly killed and rapidly covered over with sediment. Among the distinctive fossils of the Upper Old Red Sandstone are species of *Asterolepis*, *Bothriolepis* (formerly confused with *Pterichthys*), *Coccosteus*, *Conchodus*, *Cosmacanthus*, *Glyptopomus*, *Gyroptychius*, *Holoptychius* (four or more species), *Phaneropleuron*, *Phyllolepis*, *Polyplocodus* and *Psammosteus*. . . .

"In the north of England sandstones and conglomerates representing the ordinary type of the Upper Old Red Sandstone emerge from underneath the Carboniferous formations, and lie unconformably on Silurian rocks and Lower Old Red Sandstone. Some of the brecciated conglomerates have much resemblance to glacial detritus, and it was suggested by Ramsay that they have been connected with contemporaneous ice-action. . . . In South Wales and the border counties of England, as already stated, the Carboniferous series passes down conformably into the Upper Old Red Sandstone, which cannot at present be separated from older parts of the system." [34]

Describing in more detail the Upper Old Red Sandstones of Kinross, A. Geikie states:

"Well-bedded red, grey, purple, and white sandstones, with thin partings of red shale or marl, may be seen for nearly two miles up the Glen Burn. These strata are often flaggy or false-bedded, and many of them are crowded with 'galls' or flat pellets of red or purple clay. Some of the beds of this character contain plentiful fragments of *Holoptychius*, which may be readily detected by their white or yellowish color on the dark ground of the stone. A good locality for searching for ichthyolites will be found at the upper end of the Gospetry fir-wood, above the road that passes by Moors of Kinnesswood and Lappiemoss. A thin band of yellowish sandstone, well charged with clay-galls and containing fragmentary fish-remains, crops out at the foot of the scar on

[34] Text-book of geology, 1903, pp. 1010-1012.

the left bank. A hundred yards further up, similar remains occur in a band of red sandstone at the bottom of the low cliff.

"The sandstones become more massive and false-bedded as they ascend in the series, till at a point in the stream a little more than a mile southeast from Easter Gospetry they are succeeded by the thick zone of soft white and yellow sandstones already mentioned. These differ considerably from the strata below them, not merely in color, but in texture, composition, and structure. They are, as a whole, coarse in their material, which consists of well-rounded grains of quartz, not infrequently blue, and of rolled grains of felspar. The coarser layers show well the composition of the sediment, which must have been derived from the decay of rocks wherein water-clear and also blue hyaline quartz, as well as white and pink felspar, abounded. So felspathic and decayed are some bands of these sandstones that, when a handful of their substance is thrown into water, a white cloud of clay particles immediately appears. A distinctive feature of this group of strata is to be found in their remarkable false bedding. One bed may be seen with its current lamination inclined towards northwest at 35°. This lamination terminates upward along a sharply-defined plain forming the bottom of another bed in which the layers dip southward at 3°. These, again, are truncated in the same sharp way by another bed in which the layers dip northward at 5°, while above it lies a band in which the laminæ are inclined in the same direction at 15°. These structures furnish a suggestive picture of the shifting water-currents by which this group of pale sandstones was accumulated.

"These white and yellow sandstones appear to form the uppermost zone of the 'Dura Den beds' of the east of Fife. Though they have not yielded here the same remarkable assemblage of fishes as that for which Dura Den itself has long been celebrated, they contain fish-remains, as was recently ascertained by Mr. B. N. Peach. They perhaps only need to be quarried and laid open in a fresh and unweathered condition to supply a similar series of ichthyolites." [35]

These descriptions suggest in the conglomerates, breccias, and false-bedded sandstones with fish fragments a greater degree of torrential river action than was characteristic of most of the Lower Old Red. Hickling calls attention also to the prevalence of the cornstone type of deposit. The soft white and yellow sandstones with well rounded grains of quartz and remarkable false-bedding suggest the agency of wind as an agent of accumulation. There is nothing in the descriptions, however, which indicates that fluviatile transportation may not have been dominant. It is true, Goodchild states that the sandstones are often full of desert-sand grains and are highly false-bedded in places, like an old desert sand-dune.[36] But little judicial weight can be attached to this statement, however, since Goodchild nowhere recognized the possible importance of fluviatile aggradation in humid or semi-arid climates as distinct from true desert conditions. There is nothing to indicate in Goodchild's work but that all red, fossil-barren, and false-bedded sandstones are of desert

[35] Geology of central and western Fife and Kinross-shire. Mem. Geol. Survey Scotland, 1900, pp. 34, 35.

[36] The older Deutozoic rocks of North Britain. Geol. Mag., Dec. 5, vol. i, 1904, p. 592.

origin and the false-bedding a mark of eolian agency; yet it is clear that false-bedding of a certain type is characteristic of river deposits, whereas that due to dune structure is strikingly different. It is, furthermore, the millet-seed texture of sandstones, the rounding of the very fine sand, which is a distinctively eolian feature, rather than the mere occurrence of rounded grains in a coarse sandstone. There are undoubtedly both fluviatile and marine sandstones which show remarkable cleanness and rounding of coarse sand grains.

That the Upper Old Red is dominantly fluviatile, not eolian and torrential in its nature, is indicated further by the following description by A. Geikie of the Dura Den section in eastern Fife, from which the greater number of the fossil fish from this formation have been obtained:

> We may conclude that in this district, as further to the west, the prevailing rock is sandstone, which in the lower half of the formation is of dull purplish to brick-red colors, while in the upper half, as has been already mentioned, yellow and white tints prevail, though by no means to the exclusion of the red. With the sandstones are associated seams of red marl or clay, in which layers of sandy limestone or cornstone may occasionally be noticed. Here and there thin bands of fine conglomerate may be seen, the pebbles consisting sometimes of well-rolled quartz, sometimes of andesites, from the older part of the Old Red Sandstone.
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> In the fish-bearing strata of the Carboniferous formations of this district detached scales and teeth are much more frequent than entire skeletons, and are almost always associated with abundant coprolites and remains of ferns and other vegetation. But at Dura Den the conspicuous feature is the crowding together of entire specimens on the chief ichthyolite platform. The fishes appear to have been suddenly killed in shoals and to have been entombed among the fine sandy silt on the spot, before large numbers of them had time to decay and fall to pieces and before any agitation of the water of the lake could separate and scatter their scales and bones. Various causes have been suggested for such rapid and extensive destruction of life, such as earthquake shocks, the escape of mephitic gases, and the isolation of the animals in pools where the water ceased to be adequately oxygenated. No definite clue, however, has been found either in the strata themselves or in the position or condition of the fish-remains to indicate what may have been the agent that in this instance wrought such havoc in the fauna.
>
> Elsewhere in Fife and in Kinross-shire, though traces of fish-remains are frequent enough in the Upper Old Red Sandstone, they consist for the most part of single scales and fragments of bone, especially belonging to the genus *Holoptychius*. As they are not restricted to any definite horizon, but seem to range throughout the whole formation, it would appear that the same general conditions of sedimentation prevailed from the beginning to the end. The Dura Den sandstone does not, therefore, so much mark a definite palæontological subdivision as an exceptional area where the organisms were rapidly killed and buried in great numbers. Similar yellow sandstones occur interleaved with red bands along the outcrop of the higher portion of the formation westwards all through the Howe of Fife into Kinross-shire. No such fossil riches as those of Dura Den have been met with, however, in these more

westerly prolongations of this type of strata. This failure may arise either from there never having been any such exceptional mortality among the fishes in the western waters, or from no fortunate section having yet exposed any rival to the fish-bed of eastern Fife.[37]

The well rolled quartz pebbles, the scattered fish scales, the partings of clay, all testify to a dominantly fluviatile origin of the beds. Of the various causes which Geikie cites as possible explanations of the concentration of the well preserved fish fossils into certain strata, the one which falls naturally into line with the interpretation given to the beds in this article is that of fish crowded into pools inadequately oxygenated.

Taken as a whole, the descriptions of various writers, although indicating a persistence in the Upper Old Red of fluviatile deposition, do suggest a more intermittent and torrential character of rivers, implying more contrasted seasonal conditions of alternate rainfall and aridity than during most of Old Red Sandstone times. True desert climates did not, however, prevail, since no marked wind-facetting of pebbles has been noted, the cross-bedding seems to be more fluviatile than eolian, and the limy deposits are not associated with salt and gypsum.

Geography of the British Isles in Devonian Time

The Old Red Sandstone formations have been described in some detail. A brief consideration may now be given to the possible sources of material and the indications from such lines of evidence in regard to the limits of the basins as drawn in figure 1.

In Cornwall and Devonshire is a fairly complete Devonian record, most of which holds marine fossils. The basal formations are found to overlap toward the south. There are indications also in Brittany of Lower Devonian land having existed in this southwesterly direction. Toward the north of Devonshire the sediments thin out against an axis of non-subsidence located along the line of the present Bristol Channel. The open Devonian shallow sea lay to the southeast and the fossiliferous rocks of Cornwall and Devon represent its near-shore deposits.

The southern part of Ireland is largely underlaid with the Glengariff beds. These consist in their lower part of hard green and purple grits with subordinate beds of slates, but in the higher part slates of red and purple tints predominate over the grits. No fossils have been found in them, though they are brought up along broad anticlinal flexures which range from the west coast of Kerry to the eastern parts of Cork. Their thickness has been estimated at 8,000 feet, but when due allowance comes to be made for folds and faults it may prove to be much less.[38] The

[37] A. Geikie: The geology of eastern Fife. Mem. Geol. Survey of Scotland, 1902, pp. 57, 59.

[38] A. J. Jukes-Browne: The building of the British Isles, 1911, p. 111.

Upper Old Red is also present and graduates upward into the Coomhola beds and the Carboniferous slate. The Coomhola beds are alternations of gray and brown grits with bands of dark gray slate and hold a marine fauna. The unfossiliferous state and physical nature of the Glengariff suggests strongly that the beds are not of marine origin. It appears likely that they were mostly laid down on delta plains which toward the southeast were built out into the interior sea. In the Lower Devonian the South Irish basin of deposit was restricted, but in the Upper Devonian sedimentation advanced widely over central Ireland. Figure 1 indicates the relations of the basins of Lower and Middle Old Red Sandstone and the boundary of the South Irish basin as given by Jukes-Browne.

The Lower Old Red sediments which made the Glengariff beds did not, however, come in large measure from central Ireland, since the post-Carboniferous erosion of anticlines reveals the fact that the Upper Old Red sediments rest on Silurian strata. In southeastern Ireland, south of Dublin, there is a large granite massif intruded probably during the Lower Devonian into Ordovician rocks. This resulted doubtless in some subsequent erosion from this region, but for adequate sources of supply for the great volume of the Glengariff beds, especially for the parts of earlier date, it would appear that we must look to Precambrian areas to the south, west, and northwest now mostly concealed by ocean waters.

The Old Red of the Welsh basin rests on Silurian rocks. Silurian and Ordovician strata mantle, furthermore, the greater part of Wales. If the Old Red had been derived from these formations, either folded or unfolded, it would seem that this Devonian erosion should have destroyed much of the formations in areas where they are now exposed. Therefore probably the greater part of the Old Red sediment could not have come from this region of earlier Paleozoic rocks. The region of northwestern Wales and Saint Georges Channel must be looked to as a chief source of supply, though eastern England may also have contributed; the evidence from that region is, however, buried beneath younger strata.

In the Caledonian basin are great quantities of igneous outpourings, so that the amount of surrounding erosion which is implied by the sediments is much less than the volume of deposit. Later denudation has evidently, however, removed the Old Red from great areas, reducing the apparent volume of the original deposits, since the boundaries are now largely faults against which the beds dip with great thicknesses. Isolated remnants on the Firth of Lorne and in northernmost Ireland indicate important extensions of the original basin, or the existence of closely adjacent basins, in these regions. The character of much of the sediment does not suggest a very distant source. Jukes-Browne has shown one great lake, whereas A. Geikie believed in several smaller lakes. The in-

terpretation given in figure 1 is that of several contiguous and partially confluent alluvial basins. The geographic boundaries are thus taken as intermediate between those given by Jukes-Browne and those by Geikie. This position, it is thought, is justified on consideration of the nature of the sediments, the later crust movements, the consequent denudation, and, in other regions, the nature of intermontane basins.

The Caledonian basin holds mostly Lower Old Red deposits; the Orcadian basin contains sediments whose age is Middle Old Red. The two basins, however, probably overlapped, deposition beginning in the north before it closed in the south. An overlap of the same nature may very likely have occurred between the Orcadian and Shetland basins.

The Shetland basin has been delimited from the Orcadian, since Flett and Traquair have shown that it holds a younger fish fauna. It does not seem probable, furthermore, that the same individual basin should have extended as far as eastern Russia, as some writers have suggested.

This map of Great Britain in the Devonian period may be compared also with the recent paleogeographical map published by Schuchert.[39]

In a larger view of Britain as a part of a Devonian continent, it is seen to have lain between a sea on the southeast and a mountain system of unknown extent on the northwest. It was a region furrowed with mountains and basins. But erosion in a region of strong relief is so rapid that the uplands adjacent to the basins were kept worn fairly low and the basins were in general maintained in a graded condition by the rapid inwash of alluvial deposits. On these basin plains shallow lakes spread at times but were inconstant in character. The greater supply of sediment came from the northwest, the direction of the greater mountain system. Only the margins of this ancient upland remain exposed above the waters of the Atlantic, showing now as the Precambrian rocks of western Scotland and northwestern Ireland.

Our more definite knowledge is restricted to the regions which were originally basins and which are still above the sea. To those Devonian basins, the early Tertiary basins, with their deposits in the Rocky Mountains of the United States, may in many respects offer a close analogy. In the early Tertiary the Cordillera had not yet attained its high plateau character. Mountain-making was in progress and enormous quantities of waste were poured as fluviatile deposits into intermontane basins. Continued tectonic and igneous activity kept deforming the basins and shifting the areas of deposit. Volcanic dust and breccias added important quantities of material to that derived from erosion. Oscillations in climate took place, the changes being on the whole toward semi-aridity, but true desert conditions were of limited occurrence. The Rocky Moun-

[39] Text-book of geology, 1915, p. 716.

tains, then, from the tectonic standpoint, may offer an instructive analogy, whereby the Old Red Sandstone deposits of Britain may be interpreted in the light of the knowledge gained of the more recent past.

General Conclusions on Devonian Climate in British Isles

The absence of even discontinuous and local beds of coal implies a rather complete desiccation of the marshes during the dry season. The same conclusion is reached by the prevalence of mud-cracked surfaces in the finer-grained deposits, shown especially in the Orcadie basin. Many of the conglomerates are rather highly feldspathic, and both the sandstone and flagstone groups are characterized by the presence of a large amount of limestone deposited from fresh waters. This assemblage of characteristics marks especially the floodplain deposits of regions with a semi-arid climate or at least with a pronounced dry season, such as the upper floodplain of the Ganges.

The significance of the dominantly red color has been discussed. It implies the regular recurrence of seasons of dryness, effective for maintaining the iron in fully oxidized form.

Furthermore, it was noted that the flagstone groups, in places characterized by their mud-cracks, were also rich with fish remains, and that on certain surfaces the fossils are crowded thickly together and preserved in such detail as to show that they died where their remains are found. The natural explanation in connection with the hypothesis of floodplain origin is found in the existence of seasons of drought which first concentrate the fish into shallow lakes on the floodplain and, by further evaporation of the water bodies, kill them. For death to take place complete desiccation is not necessary, but merely sufficient concentration to make the waters too crowded and foul for respiration. Such a sheet of water, deficient in oxygen and protecting the remains from complete decomposition, may explain the presence of much of the bitumen found associated with the fossils and into which they are sometimes bodily transformed.

These features indicating that the climate had neither the humidity nor the seasonal uniformity which marked the coal-making portions of the Carboniferous limit the climate in one direction. Facts which tend to delimit it in the other direction are complete absence of salt and gypsum deposits; gray color and bituminous composition of the flagstone groups; presence of ferns, logs of trees, and roots; presence in some of the basins of thin coaly laminæ and surfaces of sedgy, matted vegetation.

These facts converge from the two directions of dryness and wetness and serve to narrow down the determination of the climatic conditions in the regions of accumulation. In some respects they may appear at first

sight to overlap and conflict, as, for instance, the presence of gray and green colors and a bituminous composition, together with a striking prevalence of mud-cracks. Mud-flats covered with sedgy vegetation and black in color may, however, be cracked to depths of as much as a foot without complete drying out and consequent oxidation of the organic matter, the clay having the consistency of a stiff gelatine. Some overlapping and conflict of evidence is, however, to be expected between different horizons, or possibly the same horizon in different basins, since it is known that the Old Red Sandstone represents a long period of time. There is, therefore, no reason to believe that the climate was strictly uniform throughout. The characteristic oxidation is favored by warmth. The breccias which some geologists have regarded as possibly glacial in origin are in all probability torrential deposits from adjacent mountains. The Devonian trees seem to have grown in swamps and do not show growth rings as would be expected in a climate where growth in swamps would be seasonally arrested by cold. The temperatures were therefore probably mild at the lower elevations. The semi-aridity seems to have become more marked in the Upper Devonian, possibly giving rise then to notable proportions of eolian and torrential, as distinguished from fluviatile deposits.

It may give definiteness to thought to point out how wide-spread are present regions which seem to answer to the climatic limitations as previously determined. An inspection of a chart of the seasonal distribution of rain[40] shows that climates with periodic rains are characteristically continental, the only notable exceptions being the eastern half of North America, Europe north of the Alpine cordillera, western Siberia, and limited equatorial regions. Excluding, however, cold climates and those marked by aridity or high semi-aridity, the general type of the presumed Devonian climates of Scotland is found at present broadly developed over South America east of the Andes and as far south as Buenos Aires except for two limited regions—the one a narrow equatorial belt, the other the coast of southeastern Brazil. Such warm climates, marked by periodic rainfall and drought, also exist over central Africa, except in the equatorial Congo basin. They are also developed in Indo-China, more particularly over the southern alluvial basins and deltas. Over the greater portions of these regions the annual rainfall is from 40 to 80 inches, a fairly small amount for the Torrid Zone; and over considerable portions, especially the indicated portions of Africa and all of Indo-China, the rainfall is so concentrated that from 20 to 30 per cent of the annual precipitation falls within a single month.

[40] See Bartholomew's Atlas of Meteorology, 1899, plate 19.

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INFLUENCE OF SILURIAN-DEVONIAN CLIMATES ON THE RISE OF AIR-BREATHING VERTEBRATES [1]

BY JOSEPH BARRELL

(Presented before the Society December 28, 1915)

CONTENTS

[1] Presented in abstract to the American Society of Vertebrate Paleontology, December 26, 1907, through the kindness of an invitation extended by the Society at the request of Prof. R. S. Lull. (See abstract in Science, 1908, vol. xxvii, pp. 254, 255.) Some of the arguments on this subject are found also in a paper by the writer in Bull. Geol. Soc. Am., vol. 18, 1907, pp. 472-474. The writer is indebted to his colleagues, Prof. R. S. Lull, for carefully reading the original manuscript in 1908 and suggesting some changes, and Professors Charles Schuchert and L. L. Woodruff, who have read the manuscript as revised in 1915. Professor Schuchert's advice has been of especial value, from his large knowledge of the literature of paleontology and his perception of its bearings. He has also discussed this subject to such an extent as was appropriate for that place in his recent "Text-book of Geology." The theme of the paper is in sequence to certain studies on sedimentation published by the writer in the Journal of Geology in 1906 and 1908, but has been withheld until papers on the Devonian, which were necessary to form a logical basis for the arguments of the present subject, should have appeared. These latter papers are entitled, first, "The Upper Devonian delta of the Appalachian geosyncline," published in the American Journal of Science, vols. xxxvi and xxxvii, 1913 and 1914; and, second, "Dominantly fluviatile origin under seasonal rainfall of the Old Red Sandstone," published in connection with the present paper.

Manuscript received by the Secretary of the Society January 25, 1916.

Introduction and Summary

The problems of organic evolution have many aspects and ramify into many fields of science. The subject was at first embraced chiefly in the field of the old-time naturalist—zoologist or botanist—but the problems of variation and heredity have passed into the hands of the experimental evolutionist; and there are other problems whose answers are found in the geologic record, but these are of two rather opposite aspects. On the one hand, the paleontologist specializes particularly on the succession and relation of fossil faunas or floras. On the other hand, it is the field of physical and historical geology to restore the ancient environments. The relations of the environments to the biotas is a field wherein physical geology and paleontology meet, to give a better understanding of the underlying causes of organic response and progress. It is from the standpoint of physical and historical geology rather than from that of paleontology that the present study is made.

A summary of the paper is as follows:

It is shown to be probable that fishes arose in land waters. As such they constituted primarily a river fauna. The fossil record, as known at present, shows that about the middle of Ordovician time fragments of armored fishes were occasionally drifted out to sea and worn by waves and currents. Some of these lowly fishes came later to live in brackish waters and are found in bay or marginal marine deposits. They clearly did not as yet rule the sea, nor could they then withstand the enemies which lived therein. In the later Silurian strata the spines of primitive sharks and plates of ostracoderms begin to be found more abundantly, but only in a few localities and in special beds. Their life was still limited to brackish and protected waters; their normal home, serving as a center of dispersal, was apparently still within the land waters. Not until the beginning of the Middle Devonian, as powerful sharks and arthrodires, did the fishes first really begin to conquer the ocean and its former rulers. Then they began also, for the first time, to leave abundant and well preserved fossils in marine deposits unrelated to the shores.[2]

[2] Professor Grabau has quite independently reached very similar conclusions in regard to the geological history of ostracoderms and fishes. These are expressed in his "Principals of stratigraphy," pp. 1033-1035, 1913. Since then Grabau has transmitted a manuscript on The Devonic fish fauna of America, to the Michigan Geological Survey. This is still unpublished. In it he discusses in detail the problem of the habitat of the

In contrast to the comparatively continuous and widely developed mantle of marine sediments of the early Paleozoic with its wealth of fossils, the record of the land waters is so meager that practically nothing is known of its life. With the opening of the Devonian, however, the formation of intermontane basins, especially in northwestern Europe, gave rise to mixed river, swamp, and lake deposits shut off from the sea. There were thus created physical conditions suitable for the preservation of fossils of the fresh waters. Here, in the Lower Old Red Sandstone, numerous species of ostracoderms and acanthodian sharks are preserved. The record shows that fishes were at this time well represented in the fresh waters, while hardly as yet able to survive in the sea.

At the opening of the Devonian the acanthodian sharks were the dominant fishes in the continental waters. Dipnoans and crossopterygians were not in evidence in the regions where the fossils have been preserved. In the Upper Devonian the sharks were gone from the fresh waters, but the crossopterygians had risen in that environment to a dominant place. Their ability to utilize air adapted them better as river fishes to warm climates marked by alternation of wet and dry seasons. It was a semi-arid rather than an arid or humid climate which characterized the regions of the Old Red Sandstone during late Silurian and most of Devonian time. The climate of much of the torrid zone at the present time may give the best illustration of the conditions of temperature and rainfall which in the Silurian and Devonian, but especially in the later Devonian, characterized the northern hemisphere. The few remaining dipnoans and crossopterygians still live as fresh-water fishes under similar climatic conditions.

The amphibians are represented in the later Paleozoic by certain skeletons preserved in the accumulations of coal swamps, but more abundantly by footprints in formations having the character of semi-arid floodplain deposits. As the record is traced backward, the skeletons disappear, and the oldest abundant traces are footprints left in shales and sandstones, chiefly red in color, of Lower Carboniferous age. These are the deposits of rivers which were in the main subject to seasonal shrinkage in markedly semi-arid climates. The footprints lead us back to the habitats of river fishes, the ancestors from whom they sprang. There are here con-

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Paleozoic fishes. The papers of Grabau and the writer, although similar in conclusions, are mostly supplementary in nature to each other, as is apt to be the case with independent work. Grabau enlarges especially on the American fish faunas, and regards even the Middle and Upper Devonian faunas of the central States as not yet completely marine, although the fossils he notes are found in marine associations. This is a problem somewhat aside from the present paper. Consequently, although the present writer has accepted what seemed to him more probable, a truly marine existence for fishes from the beginning of the Middle Devonian, the difference of opinion on this topic does not involve any of the principles under discussion in this paper.

verging lines of evidence that the rise of amphibians came not from the sea, but from the land waters. The exposure of the tidal zone alternately to water and to air had, then, nothing to do with the origin of lungs.

Having made this study of environments, the argument passes on to an analysis of causes leading to the rise of amphibians. The law of probabilities shows that the directive influence of external factors is necessary to guide the development of old organic structures into combinations of new structures which shall be efficient under a combination of new conditions. Natural selection, although not now regarded as an explanation of most minor organic variations and the development of new species, is nevertheless a broad controlling force which compels development within certain limits of efficiency. What, then, were the causes which controlled the passage of fishes into amphibians? The chief cause is found to have been the nature of Silurian and Devonian climates. The warm and stagnant waters of the dry season compelled those fishes which should survive to make larger and larger use of air. The organic nature of fishes was at that time happily able to vary in pace with the demands of changing environment.

The evidence is regarded as strong that the air-bladder was originally developed as a supplemental breathing organ, although in modern fishes it has been mostly diverted to other uses. Among certain Devonian fishes, living under more and more strenuous climatic conditions of seasonal dryness, the use of the air-bladder for respiration became essential, and with the diminishing availability of the waters of certain regions the gills in those species which survived this crisis in evolution became correspondingly atrophied. The amphibians thus arose under the compulsion of seasonal dryness.

In conclusion, it is noted how the particular method of accessory respiration which was adopted by the ancestors of amphibians was only one of several methods which have been used by fishes. This method of accessory respiration permitted the rise of land vertebrates and determined the future lines of evolution, but another choice of the mode of respiration might have led to more rapid progress—a progress which would, however, have been directed into somewhat different lines.

Lastly, the rise of amphibians from river fishes in an epoch of semiaridity was one of the major steps in the evolution of man. Matthew has developed the evidence for the hypothesis that "the evolution of land life in adaptation to recurrent periods of aridity supplies a satisfactory background of cause for the whole evolution of the higher vertebrates." [3]

[3] W. D. Matthew: Climate and evolution. Annals of the New York Academy of Sciences, vol. xxiv, 1915, pp. 171-318 (p. 181).

This article emphasizes this view and elaborates the evidence and its bearings on the first appearance of land vertebrates. Climatic oscillation is a major ulterior factor in evolution.

Environmental Conditions surrounding the Rise of Amphibians

PROBABLE EARLY HISTORY OF CHORDATES

This paper is a study of the compulsion of changing environments on the progress of evolution, illustrated in the rise of the first land vertebrates. Then was determined for all later time the general body plan, which, with its initial limitations, and yet its advantages, was to be molded and adapted to all the various modes of vertebrate life. But the remote ancestors of amphibians had already been in existence for geologic ages before the first vertebrates emerge from obscurity and write their existence plainly in the geologic record. During those previous ages the environmental and organic forces were already at work, which gave rise in the fullness of time to the Silurian and Devonian fishes and determined a certain group of them capable of becoming ancestors of amphibians. A discussion is called for, consequently, of the probable early history of chordates as an introduction to the central problem of the paper. The evidence is mostly indirect and is not of the same order of certainty as that bearing on the rise of amphibians, but nevertheless it points somewhat definitely toward certain conclusions.

The lingering and aberrant representatives of the early chordate stem are now found in oceanic environments, as balanoglossus, ascidians, and the lancelets. This present restriction may be thought suggestive of an original marine origin. It should be distinguished, however, from proof, since the actual ancestral line of fishes is not known and the greater breadth and geological stability of conditions on the margins and floor of the ocean would favor the longer preservation there of such archaic types as had once become established in that realm. The most primitive chordates, balanoglossus and amphioxus, burrow in the sea sands and live somewhat after the fashion of annelids. It seems that at a time when chordates may have been more abundantly of this type they should, like annelids, have spread into bottom sands and muds of both fresh and salt waters. Even if such primitive chordates had once existed in fresh waters, they would have left nothing more than worm burrows, no distinctive fossil evidence of their existence. The ultimate place of origin of chordates can not, then, be safely argued to have been the sea; much less can the presence there of balanoglossus and amphioxus be held as evidence of a marine origin of fishes. They leave the place of origin an open question, to be decided by other lines of evidence.

Both marsipobranchs and fishes show a ready adaptation to the differences of salinity between fresh and salt waters. In many species the individuals pass from salt to fresh waters for breeding purposes, certain fishes, such as the eels, possessing, however, the opposite habit. The greater safety of fresh waters as an environment for the young is a sufficient explanation of this common habit among fishes; yet the ready adaptation to different salinities in contrast to the narrow limits common in other phyla of animals is suggestive that even in early times chordates were not limited in their range by the low or high salinity of the waters, but by the enemies of the one or the other environment.

The habits of the lampreys are most suggestive in this connection. These lowest of craniate vertebrates live both in fresh and salt water and ascend the streams to spawn. They are effective swimmers, capable of stemming the currents of swift rivers and using the same power to overtake the fishes which they make their prey. The only known fossil representative, *Paleospondylus gunni* from the Devonian, was found, furthermore, in a fresh-water formation—the Old Red Sandstone of Caithness. Although an apparent and perhaps sufficient cause of the spawning habits of the lampreys is to be found, as in true fishes, in the greater safety of the larvæ, yet in such an archaic form it is likely to be an equally archaic habit. The more archaic the habit, the more likely it is to signify that the fresh waters were the environments within which the lampreys came into existence. In the same manner, it is seen that the laying of the eggs of amphibians in fresh water is an embryological necessity reminiscent of their original home before their race grew to possess lungs and legs.

The diversification of true fishes, when they assume a dominant rôle in the Devonian, points to a long previous evolution, yet the marine record of their previous existence is almost negligible. Compare the abundant and well preserved fossils of brachiopods, trilobites, and cephalopods in the Cambrian and Ordovician rocks with the rare and fragmentary evidences of fishes. Yet the teeth, spines, and plates which ostracoderms and acanthodian sharks possessed in the Ordovician should have permitted ready fossilization if representatives of these subclasses were then broadly present in the sea.

The lowest well known occurrence of fishes in the stratigraphic column is that made known by Walcott in 1891. Near Canyon City, Colorado, the base of the Middle Ordovician (Lower Trenton) rests on the Precambrian. The basal formation is the Harding sandstone, 86 feet thick. It is overlain by from 2 to 4 feet of shale, followed by about 300 feet of limestone holding an abundant Trenton marine fauna. The Harding sandstone is without doubt an offshore formation, since it contains species

of Lingula, Orthoceras, and Beyrichia. At several levels water-worn scales and plates of fishes are found abundantly. Many of these plates belong clearly to an ostracoderm of the family Asterolepididæ. One portion of the head carapace was found. Another form, based on a calcified chordal sheath, Walcott provisionally assigned to the Chimæroidea; and another form, based entirely on separated scales, he placed within the crossopterygian family of Holoptychididæ. These latter two forms, however, have been assigned with a question mark by Eastman to the ostracoderms. With the coming in of the limestones all traces of the fishes disappear.[4] Similar fragmentary remains have since been found in some other localities in the Rocky Mountains at the same geological horizon. The indications are thus clear that the fishes at that time were already in existence and possessed structures well adapted to fossilization, but were not a part of the fauna of the open sea. Where could they have had their previous existence and where was the central home in which they continued to exist until they again appear in the geologic record? In answer, it is seen that the thickness of the Harding sandstone suggests that it consists of river-derived muds and sands. The worn fragments of fishes were brought apparently to the margin of the sea by rivers and were buried in this manner in a marginal marine deposit.

One other positive trace of fishes is known in the Ordovician. Traquair, writing in 1900, states:

"Rohon has described from the Lower Silurian (Ordovician) of the neighborhood of St. Petersburg small teeth (*Palæodus* and *Archodus*) associated with conodonts, and which seem to be real fish teeth, but not of selachians, as is shown by the presence of a pulp cavity surrounded by non-vascular dentine. It is impossible to say anything more of their affinities."[5]

The next appearance of fishes is by means of the scattered spines known as ichthyodorulites and referred to the genus Onchus. These spines belong to primitive sharks and occur in the Middle and Upper Silurian. Claypole found them in Pennsylvania; but they can hardly be regarded as declaredly marine, since, though possessing some marine associations, they are found in red shales which a little farther east have the facies of subaerial delta deposits, but are there entirely unfossiliferous. Their age is probably Salina.

The first notable assemblage of fishes is found in the stratum of fossil remains known as the Ludlow bone bed. This occurs at the top of the

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[4] C. D. Walcott: Preliminary notes on the discovery of a vertebrate fauna in Ordovician strata. Bull. Geol. Soc. Am., vol. 3, 1892, pp. 153-172.

[5] R. H. Traquair: The bearings of fossil ichthyology on the problem of evolution. Geol. Mag., Decade 4, vol. vii, 1900, pp. 464, 465.

Ludlow and lies immediately below the beds of passage into the lowest of the Old Red Sandstone formations—the Downtonian—uppermost Silurian in age. The Ludlow is the uppermost division of the British Silurian which holds marine fossils and the Downtonian sandstones represent the appearance of continental deposition in latest Silurian time. It is in a layer of the Upper Ludlow from a few inches to a foot in thickness and rich in carbonate of lime, phosphate of lime, iron, and bitumen that most of the fossils are crowded and which constitutes what is called the Ludlow bone bed.[6] The fauna, as listed by Phillips,[7] contains in notable abundance one species of pelecypod, two of gasteropods, three of brachiopods, two species of shark spines belonging to the genus Onchus, four species of Ostracoderms, and plant remains. For the whole of the Upper Ludlow, Phillips gives ten genera and fourteen species of fishes, all ostracoderms except for the two species of Onchus.

The Downtonian rocks above the Ludlow are dominantly red and yellow, fossil-barren, false-bedded sandstone, representing the first outbuilding of the subaerial Old Red Sandstone deposits across this region. Rare fossiliferous bands of a different sedimentary nature carry a brackish-water fauna and represent such incursions of the shallow sea as occur from time to time over the outer parts of all delta regions. This fauna contains fishes which Traquair has determined to be sharklike ostracoderms associated with more typical ostracoderms; but no true acanthodian sharks have been found.[8]

The sharklike genus of ostracoderms, Thelodus, has been traced upward from the Ludlow rocks into the higher horizon of the Lower Old Red Sandstone of the Caledonian basin at Turin Hill, where marine associations are no longer in evidence. Here are found, however, a number of species of true acanthodian sharks, mostly of the genus Climatius.[9] It is striking that this first well known shark fauna should be found in rocks which are clearly non-marine. Their environment at that time appears to have been somewhat more restricted than was that of the far lower ostracoderms. Throughout the time of deposition of the Lower Old Red Sandstone of the Caledonian basin, so far as the fossil record indicates, the primitive sharks reign supreme, the ganoids and dipnoans not yet appearing. From their sudden invasion, strong in numbers in the following Orcadian fauna, it is to be inferred that these subclasses were in

[6] Murchison: Siluria, 1859, pp. 148-153.

[7] John Phillips: Manual of geology. Edited by Etheridge and Seeley. Part ii, 1885, pp. 127-138; especially p. 129.

[8] Trans. Royal Soc. Edinburgh, vol. xxxix, part iii, 1899, pp. 827-864.

[9] A. S. Woodward: Catalogue of fossil fishes, part ii, 1891.

G. Hickling: The Old Red Sandstone of Forfarshire. Geol. Mag., Decade 5, vol. v, 1908, pp. 398-401.

existence during the earlier time, but were more restricted in distribution and apparently did not as yet dispute the habitat of the primitive sharks. The latter also, as previously noted, were, in those early stages, more restricted than the ostracoderms, appearing less abundantly than the latter in the brackish embayments of the sea, though showing themselves more abundant in the first clearly fresh-water fauna.

Each higher class of chordates is thus found to be more restricted at first than the lower groups. When higher and lower are both existent, the lower are found as earlier waves and farther from the original center of evolution. This is a well known principle when applied to mammalian evolution in the Tertiary. For mammals the record is exceptionally clear. For the earlier chordates it is scanty, but, so far as it is clear, points to a center of evolution within the land waters. From that original home the primitive chordates which still exist are farthest removed.

The nature of the early vertebrate record is strikingly like the record of the Eurypterids and receives here the same interpretation which Grabau and Miss O'Connell have given to their history.[10] The bulk of sands and muds deposited in the seas is of river origin, and the currents are known to bring with them in abundance certain kinds of land life, especially fragments of vegetation. The material given by a strong and sediment-laden river to the weak waves of a shallow sea is deposited near shore and is subjected to very little wear, but will probably bear evidence of marine deposition. With lesser sediment and stronger wave action, resistent fragments, like the teeth, spines, and plates of river fishes, will be more worn, but as rare fragmentary fossils will continue to occur. Besides these fragments brought by the rivers, there is a tendency for the living fauna to spread as far as it may, and consequently forms may live in brackish waters and leave fossil evidence of that fact at a time before they had spread into a truly marine habitat.

But if it be true that fishes originated in fresh waters, why is the early evidence known chiefly from scanty remains deposited in the margins of the sea? This requires a digression on those conditions of continental deposition which render such deposits generally unfavorable for the preservation of fossils.

Rivers deposit their sediment over floodplains in time of flood. During the low-water stages these plains are exposed to the air and their materials

[10] A. W. Grabau: Early Paleozoic delta deposits of North America. Bull. Geol. Soc. Am., vol. 24, 1913, pp. 399-512; Relation of the Eurypterids to their environment, pp. 498-499; Principles of stratigraphy, 1913, pp. 1029, 1030.

Miss M. O'Connell: Distribution and occurrence of the Eurypterids. Bull. Geol. Soc. Am., vol. 24, 1913, pp. 499-515. Her complete paper, entitled "The habit of the Eurypterida," will soon be published as one number of the Bulletin of the Buffalo Society of Natural Sciences, 1916.

are oxidized. They are, in addition, leached of soluble matters by rain and ground waters. In the low-lying portions permanent waters may exist, giving rise to swamp and lake deposits; but where the dry season is prolonged, these permanent waters shrink in area. Where, on the contrary, there is no marked dry season, the greater part of the floodplain may be kept saturated with water. This saturation, by preventing atmospheric oxidation, will lead to the accumulation of shales which are dark with carbon, or may even give rise to wide-spread coal formations.

In climates with marked dry seasons, on the contrary, the floodplain deposits are yellow, brown, or red; but, on consolidation into rock, the color, because of the partial elimination of the water from the ferric oxide, becomes more customarily brown or red. The deoxidized bands, which may be interstratified, will turn to olive green. The Silurian and Devonian continental deposits are commonly such brown and red formations, with minor amounts which are green or gray in color. Such formations are peculiarly unfavorable for the preservation of organic remains, for their high oxidation implies a maximum opportunity for the destruction of organisms at the time of burial.

The similar red shales and sandstones of Triassic age in Connecticut preserve innumerable footprint impressions, testifying to an abundant life; yet fossils are extremely rare, and the skeletal forms of but few of the very many species of vertebrates which made the footprints are known. Even the greater of the dinosaurs which inhabited this region left no record of their existence save in their gigantic birdlike tracks. Fishes which must have lived freely in the flowing waters are preserved only in the rare bands of black shale.

This evidence points to the conclusion that, even if the fishes were an abundant fauna in the continental deposits of the Silurian, they would not be preserved in them as fossils save under the rarest of circumstances, as impressions of scales, plates, or spines in variegated shales or fine-grained sandstones. Such fossils are found in the Devonian, but in the Silurian the spread of fishes was not yet so wide and the aridity was at times more intense. The nature of the geologic record is, then, not in disagreement with the hypothesis that the central habitat of fishes in the Silurian may have been the fresh waters. The absence of fossils from the river deposits and their rare preservation in the marginal waters of the sea does not prove, on the other hand, that fishes were marine. The case must be judged by other lines of evidence.

Going back of the Silurian to the Ordovician, the absence of freshwater fossils is judged to be owing chiefly to physiographic rather than to climatic causes. The climate was such at times as to give rise to marine

deposits rich in carbon, but the low altitude of lands and the wide spread of shallow seas reduced terrestrial deposits to a minimum. The same conditions apply to the Middle and Upper Cambrian. Thus, until the opening of the Devonian, our knowledge of the life of the lands is peculiarly meager in comparison to our knowledge of the life of the sea.

Let us turn to another line of argument. The zone of brackish water is restricted to discontinuous embayments. The nature of the waters is transitional between those of sea and land. It is a habitat, consequently, which is not the center of dispersal for any class of organisms, but its faunas have greater relationships to the sea than to the land. Where brackish embayments occur in regions of deposition, they are most commonly marginal to deltas and result from the shifting struggle between land and sea. In a dry season the salinity of some embayments may be higher than that of the open ocean. In the season of flood the river distributaries may rise or shift and inundate these bays with mud and fresh waters. It is only the hardiest of organisms, consequently, which can withstand the vicissitudes of these regions. On the one hand, cœlenterates, echinoderms, and cephalopods especially avoid the shifting sands, smothering muds, and changing waters of such habitats. Mollusks, arthropods, and vertebrates, on the other hand, show a more ready adaptation to these conditions, and it is from these phyla especially that the brackish waters are peopled. But the faunas are derivatives either from permanent marine or permanent fresh-water stocks. If, then, the fishes of these brackish embayments came from the sea, why are not their fossils found in greater variety, abundance, and perfection of preservation in the much wider, more continuous, and organically richer deposits of the epeiric seas? The answer which is indicated is that the primitive fishes were not there. Their theater of evolution was elsewhere. Only a few pioneer species, or the bodies of dying individuals, or their water-worn and scattered plates and scales, were washed out to sea. They were, in Ordovician and Silurian times, creatures of the land waters. The outskirts of their habitat were in the brackish embayments. In such embayments or in near-by marine waters the chances of geological preservation were, however, increased. The recurrence of dermal plates and spines in the deposits of such regions show that they possessed hard parts capable of good fossilization. In contrast to this meager showing of ostracoderm plates, scattered teeth of unknown affinities and elasmobranch spines, which constitute the earlier record, is to be noted the truly marine record, which begins with the opening of the Middle Devonian and becomes more abundant in the Lower Carboniferous. This expansion in marine fossils is the mark of a real invasion and conquest of the sea, not

beginning until the Devonian. But it has been stated that the fauna of brackish waters is more largely made by emigration from the sea. If, then, the Ordovician and Silurian fishes of these waters came from the protected land waters and were able to adapt themselves to the higher salinity of brackish waters, coming to live with brachiopods and phyllopods, what prevented them from an earlier spread into the truly oceanic realm? The answer is found in the enemies of the open sea. Not until the fishes were large, powerful, and formidable could they compete with the cephalopods, which were then the rulers of those regions. Their earlier invasion of brackish waters occurred while they were still represented by small and sluggish ostracoderms or small but active elasmobranchs.

Another and independent line of evidence suggests that the primitive fish arose in the land waters rather than in those of the sea. Chamberlin has pointed out that the body plan of the fish, primarily adapted for active swimming, is such as would be necessary for an organism living in the fresh waters, in order to stem the currents and maintain itself within its habitat. The primitive animals of the sea, on the contrary, as seen in the invertebrates, are typically sluggish and possess more or less rotund forms.[11] The comparison is best made between the floating and not the bottom living forms. It does not apply to bottom dwellers, and therefore is not an argument which can be used as to the original environment of the pre-vertebrates, such as balanoglossus and amphioxus, nor, in a measure, to the bottom-dwelling ostracoderms. It does apply to the habitat of the primitive sharks. These must have existed in Silurian if not even in Ordovician times. The sharklike Cœlolepidæ seem to show affinities between sharks and ostracoderms and are present in the later Silurian. They have raised the question in the minds of some paleontologists if ostracoderms may not be derivatives from primitive sharks. If this be the case, the origin of elasmobranchs is pushed back at least to the Lower Ordovician, although, as scattered spines, the actual testimony of their existence has not been revealed until far later in the Silurian.

In conclusion and review, it is seen that in the ages preceding the Ordovician the early chordates may have played no higher part in life than do now the annelids. In lowly wormlike forms they may have spread over the earth and have left within the more permanent and stable environments of the sea such lingering archaic representatives as balanoglossus, ascidians, and the lancelets; but against the ruling host of invertebrates they could not rise. Within the fresh waters wormlike forms

[11] T. C. Chamberlin: On the habitat of the early vertebrates. Jour. Geol., vol. viii, 1900, pp. 400-412.

could, however, attain a free life, and meeting the physical conditions of that environment became active swimming organisms. A retrogressive, sluggish, bottom-living offshoot became armored, pressed out from the locus of evolution, and because of that armor was the first group to give fossil evidence of their existence. But, as ostracoderms, they emigrated as scavengers, not as active rulers, and with the progress of evolution they were extinguished without issue. Much of the Silurian was marked by semi-arid to arid climatic conditions. It is probable that under this climatic control the ganoids found their origin. In a recurrence of these conditions in the time of deposition of the Old Red Sandstone they spread and finally dominate within the land waters over the selachians. The beginning of the Old Red Sandstone formations in the late Silurian marks a spread and diversification of the lands and their waters. The crust movements involve changing environments, a stimulus to evolution. The river and lake deposits at the same time permit the burial of organic remains. The record thus becomes clear and inference gives place to more definitely ascertainable fact.

ENVIRONMENT OF FISHES OF THE OLD RED SANDSTONE

A study of the Old Red Sandstone of the Appalachian geosyncline has been made by the writer in the field and of the somewhat similar British deposits from the reports of the British geologists. The conclusion has been reached from these studies that fluviatile deposition on the flood-plains of inland basins was at that time an important mode of sedimentation. Seasons of flowing fresh waters over the regions of accumulation alternated with seasons of exposure to the dry air. On the outer zones subaerial delta plains passed into mud-bottomed shallow seas. In the inner basins shallow lakes with shifting margins were existent at times. At other times the lakes were reduced to pans of water, evaporating in each dry season. The reduction in lake area would be due to a decrease in rate of subsidence of the basin floor or in amount of rainfall, on the one hand; or, on the other, to an increase in sedimentation or evaporation.

The great volume of the sediments which remain is only a fraction of the far greater volume which resulted from the destruction of Devonian mountains. The area of Devonian uplands which supplied the waste must have been large, and its debris was transported by rivers which passed from the uplands out over the basin plains. The fauna of these rivers would not have been greatly different in the regions of erosion from what it was in those of deposition, but fossils could be buried and preserved only in the latter regions.

The nature of the climate impresses itself on the sedimentary record,

but impresses itself even more on the flora and fauna. The climate of the Old Red Sandstone basins is seen to have been of the dominant continental nature—semi-arid. This is a type of climate which needs to be clearly visualized and separated from truly arid climates, which constitute one extreme of the climatic gamut, and dominantly humid climates, which mark the other limit. In a semi-arid climate the rainfall is seasonal, but during the season of rains is sufficient in amount for the growth of grasses or of other herbaceous vegetation. The growth of vegetation supports abundant animal life. The great grazing lands of the United States, of South Africa, and of Russia are illustrations. During the season of rains the rivers are capable of carrying abundant waste, but during the season of dryness the surface waters more or less completely disappear and the vegetation withers. Sun, wind, and possibly frost in this dry season play their parts in mechanical rock destruction and give some resemblances in sedimentation to the character of desert deposits. This character of climate is, however, as stated, distinctly different in its geological and biological effects from either desert climates or humid climates. In deserts vegetation is scanty and the chief transporting agent is wind. In humid climates a forest cover can develop, giving deeper soils and a greater ratio of chemical decay.

There are biological indications of a generally warm temperature during the Devonian period. Coral reefs grew in many places in the shallow seas of Middle Devonian time and even in high latitudes. The fossils of trees which have been preserved show no growth rings. They apparently grew where permanent ground water was available for their roots, and were able, therefore, in the absence of a winter, to grow throughout the year.

A warm, semi-arid climate in the northern hemisphere was the mean, but about this there must, in the long course of the Devonian, have been many fluctuations. During the more uniformly wet epochs the rivers would have been purer streams of more continuous flow, the shallow lakes less subject to seasonal lowering of their water level by evaporation. During the drier epochs the waters suitable for fishes would have been reduced in area, even at the times of rains, and subject to great annual diminution during the seasons of dryness. The severe restrictional effects which such oscillations about a critical mean would have on the life of fresh-water fishes is obvious.

The fish fossils are especially abundant in certain horizons of the Old Red Sandstone of Scotland. More or less perfect specimens are found in flaggy, bluish, calcareous sandstones, or in gray, calcareous shales. A bituminous cement is abundant in many cases. In the Middle Old Red of the Orcadian basin mud-cracked layers occur repeatedly in the flag-

stone groups which yield the fishes. In the Upper Old Red of Dura Den the fossils are so crowded as to imply repeated wholesale destructions of life. In contrast to the abundant and well preserved layers of fishes in the dark-colored flags, the red sandstones show only occasional teeth, scales, and spines.

The piscine fauna of the Devonian lakes was doubtless as closely connected with that of the rivers as are present lacustrine to present fluviatile faunas. A greater difference would have separated the faunas of the fresh and salt waters. It must be concluded, therefore, that the fishes lived in the rivers as well as the lakes; but their fossils are well and abundantly preserved only where the shallow lakes were occasionally rendered unfit for life. The most obvious cause of such unfitness is found in unusual seasons of dryness, reducing the shallow lakes to foul and crowded pools.

The Old Red Sandstone formations of Great Britain were largely river deposits on the subaerial surfaces of basins inclosed by growing mountain ranges. The early Tertiary basins of the Cordillera in the western United States give a fairly close analogy. In the eastern United States the Devonian record is of a different nature. There is shown, especially in New York and Pennsylvania, a continuous marine record of offshore limestones, mudstones, and sandstones. Only in the Upper Devonian do the terrestrial conditions reach broadly westward, as the Catskill delta, across these States. In the offshore sands and muds of the Devonian is a physical record deposited under more uniform physiographic conditions than was the case with the British deposits. These sediments in the Lower Devonian are largely limestones and fine-grained limy sandstones; in the Middle Devonian (Hamilton) they are thick deposits of muds and sands colored dark with carbon. In the Upper Devonian marine deposits (Chemung) carbon is wanting, and the colors are gray or olive green. This marine record seems to show an increasing aridity from Middle to Upper Devonian time, making the oxidation of sediments more complete. The marginal marine deposits are not red, however, nor do they hold gypsum or salt; so that here again is the evidence that the climate, unlike that of some other times, was not highly arid, but was rather semi-arid in its nature. Nevertheless it shows a climatic stress acting on the environment of fresh-water fishes and primitive amphibians, which increased in the Upper Devonian.

FAUNAL CHANGES IN THE OLD RED SANDSTONE

The numbers of species and genera which occur and their distribution under the different orders and subclasses have been tabulated for the

several divisions of the British Old Red Sandstone. The material for tabulation was restricted to that of certain papers which specified the horizons and localities of the fossils. Consequently the total number of fossils is not quite as large as is known, but arguments from this selected list may be more safely drawn.[12]

Distribution of Genera and Species—Old Red Sandstone Fishes of Scotland

	Downtonian		Lower Old Red		Middle Old Red		Upper Red Oak	
	Genera	Species	Genera	Species	Genera	Species	Genera	Species
Ostracodermi:								
Heterostraci	3	7	2	2	....	....	1	1
Anaspida	2	2	....	....	....	....	....	....
Aspidocephali ...	1	1	1	3	....	....	....	....
Antiarcha	....	....	....	....	2	10	2	2
Selachii:								
Acanthodii	*	....	5	15	4	17	....	†
Arthrodira	....	....	....	....	1	6	1	1
Dipnoi:								
Ctenodipterini ..	....	....	....	....	1	3	4	4
Ganoidei:								
Crossopterygii ..	....	....	....	....	7	20	3	4
Heterocerci	....	....	....	....	1	6	....	....

* Some shark spines are found, however, below the Downtonian in the Upper Ludlow. They are classified with the ichthyodorulites.

† Two acanthodians are listed by A. S. Woodward as occurring at Scaumenac Bay, Quebec. The writer has not examined this section, but most of it is doubtless continental in origin.

Eastman in 1907 published a memoir which gives lists of all the known Ordovician, Silurian, and Devonian fishes of North America.[13] These are geologically arranged and give the localities of their occurrence. The Devonian of North America was not characterized by internal basins to the extent which is found in Scotland. Except in the maritime provinces of Canada, the fresh-water beds appear to have been deposited mostly on delta plains marginal to shallow seas, and the conditions for the preservation of fish fossils of the fresh waters were much less favorable than in Scotland. In the Catskill deposits, for instance, the fossils occur mostly in the transitional zone, at the bottom of the true land

[12] The lists of fossils used are found in the following references:

Trans. Roy. Soc. Edinburgh, vol. xxviii, pt. ii, p. 452.

Silurian rocks of Britain, vol. i, p. 684.

Geology of East Fife, p. 358.

A. Geikie: Text-book of geology, pp. 1006-1012.

Geological Mag., 1904, pp. 591-602.

Geological Mag., 1912, p. 511.

The catalogue of fossil fishes, by A. S. Woodward, British Museum of Natural History, is the most complete single work. It was examined and its data tabulated for the subclasses of Elasmobranchii, Holocephali, and for the Ichthyodorulites, but the results were not found to be essentially different from the result of the lists as here compiled.

[13] C. R. Eastman: Devonic fishes of the New York formations, Mem. 10, N. Y. State Museum.

deposits, and only there, at the delta margin, were found the conditions favorable for preservation.

Broad tracts in the central parts of the continent were, however, covered with the marine waters of epeiric seas, and in the deposits of these are preserved the remains of marine fishes. In the Lower Devonian the fossils come only from the Maine-New Brunswick province. Here delta and bay conditions prevailed, and the fauna can not be regarded as truly marine. In the following tabulation of the truly marine Devonian fishes of North America all from the Lower Devonian were accordingly excluded. All from the Middle Devonian were included, but of the Upper Devonian only the fossils from Ohio, Kentucky, Iowa, and Illinois were included.

Marine Devonian Fishes of North America

Subclasses	Middle Devonian				Upper Devonian	
	Ulsterian		Erian		Ohio, Kentucky, Iowa, Illinois	
	Genera	Species	Genera	Species	Genera	Species
Ostracoderms	Shagreen granules		......	......	......	......
Selachians	8	11	9	11	12	28
Arthrodires	4	6	4	8	12	27
Dipnoans	......	......	1	2	3	5
Ganoids:						
Crossopterygians	1	1	2	2	1	1
Heterocercians	......	......	......	......	......	......

In studying the changes in the fish faunas it is to be noted that the aberrant ostracoderms never became thoroughly established as a marine order. Our knowledge of them goes back to the Middle Ordovician, but, as discussed elsewhere, the scattered fragments suggest that they are washings from the land into the margins of the seas. They seem, however, to have passed into marginal embayments; perhaps they even lived to some extent in the seas; but by the Upper Devonian the waning class was pretty well restricted to the land waters. Here it made its last stand, but died out at the end of the Devonian.

The elasmobranchs give their first marine record in the Silurian by means of the scattered and somewhat problematic spines which are grouped into the genus Onchus. This fragmentary record, as previously noted, is to be compared with the relatively abundant elasmobranch remains found in Middle and Upper Devonian marine formations. Fossils of elasmobranchs, as well as higher fishes, are absent from the probably brackish water deposits of the Silurian Downtonian, which hold the ostracoderm remains. With the opening of the Lower Devonian the

elasmobranchs are found, however, as an abundant fauna of acanthodians in the truly continental deposits of the Old Red Sandstone, where not only in grade of life, but in number of genera and species, they far surpass the ostracoderms. In the clearly marine waters of the Lower Devonian, on the other hand, their record is scanty or doubtful. In the Middle Old Red Sandstone acanthodian sharks continue in the fresh waters and compete with the crossopterygian ganoids. In the seas of Middle Devonian time, probably later than the epoch of the Middle Old Red Sandstone, the more typical sharks become abundant and compete with arthrodires. In the Upper Devonian the elasmobranchs disappear from the British fresh-water record, but maintain their ascendency in the sea.

The sharks, though primitive in organization, are powerful, aggressive, and not unintelligent fishes. Although experiencing times of repression and expansion and passing into adaptations fitted for preying on new sources of food, they have maintained their place as a subclass of powerful fishes through all later ages. The geologic record shown here in detail suggests, as previously argued, that their origin was in the fresh waters rather than in those of the sea. The spines of the Silurian genus Onchus are found in the deposits of more or less embayed or marginal waters and are to be compared with the absence of a good geologic record of the life of contemporaneous continental waters on the one hand, the absence on the other hand of elasmobranch spines or teeth among the abundant remains of invertebrates in the truly marine Silurian faunas. In the Lower Devonian a better fresh-water record has been preserved. There the acanthodian elasmobranchs are found to be the most important group of fishes and are much more abundantly preserved than in any marine formation below the Middle Devonian. Thus the actual record, although not perhaps conclusive, is more suggestive of an origin and rise of elasmobranchs, the most primitive subclass of true fishes, in the flowing fresh waters than in the sea.

At present the sharks and rays are found invading harbors; sharks pass up into the mouths of large tropical rivers, such as those of Indo-China; and one species of shark is found in Lake Nicaragua, probably trapped by the mountain growth which has made the lake basin. With this exception, however, the group is distinctly marine, though many species exhibit a tolerance of brackish water. The present marine habitat stands in marked contrast to the earliest view which we gain of them in the Lower Devonian. If the elasmobranchs were, at the present time, still a group showing free adaptations to both fresh and salt water, their disappearance from the fossil fauna of the Upper Old Red Sandstone could be

reasonably interpreted as due to local shiftings of conditions and imperfection of the fossil record. Taken, however, with their later absence from fresh waters, their disappearance from the fresh-water record of the Upper Devonian suggests a highly significant deployment of fishes during the Devonian, owing to some environmental pressure by which the elasmobranchs passed out to and became dominant in the sea, at the same time that the ganoids became dominant in the land waters. It was not until far later, especially in the Mesozoic, that the ganoids in their turn began to invade the sea. That movement is therefore not a part of the present problem.

The ganoids are first found as fossils in the Middle Old Red Sandstone, where they constituted, in number of genera and species, about one-half of the fish fauna. From the time of their appearance they dominated in their variety within the fresh waters over the competing subclass of elasmobranchs. The dipnoans appeared at the same time, at first few in species, later increasing to equal importance with the ganoids. In the Upper Old Red Sandstone these became the two dominant groups. The arthrodires, regarded now as an offshoot from dipnoans, appeared at the same time, remained to a limited degree in the fresh waters, but found in their armored head and fore body, their powerful jaws and tail, an organization fitting them to compete with the sharks in the open seas. The competition was, however, temporary, for at the end of the Devonian they became extinct, in contrast to which in the following period the sharks attained a great expansion.

If the question be raised as to what broad causes operated to bring about the differentiation in habitat between elasmobranchs and crossopterygian ganoids, the answer must be found in the nature of environment, since each, originally occupying the same habitat, became a dominant and successful group, but in separated spheres of life. The environment must have matched some fundamental difference in organization. Such a difference is found in the possession of an air-bladder, capable of use as a supplemental breathing organ in dipnoans and ganoids, contrasted to its complete absence in even rudimentary or embryonic form among the elasmobranchs. The seasonal dryness, with the shrinkage and fouling of the fresh waters, or even their complete local disappearance, was a feature of the Devonian which appears to have increased in intensity to a maximum in the epoch of the Upper Old Red Sandstone.

In the Appalachian geosyncline, as previously noted, this intensification of climatic character is seen in the contrast of the color of the marginal marine muds of the Middle to those of the Upper Devonian. The sandstones and shales of the Middle Devonian (Hamilton) are dark gray in

color. Those of the Upper Devonian which hold marine fossils begin with rocks not unlike in color to the Middle Devonian, but pass in the Chautauquan (Catskill-Chemung) into dominantly olive shales. There was, consequently, larger opportunity for oxidation and elimination of carbon, implying a greater dominance of dryness in the climate. It was a condition which the dipnoans and ganoids could partially meet, but for which the selachians were inherently unfit. This difference in power to utilize atmospheric oxygen, corresponding with the difference in need of it in the two environments, makes the probability strong that these were the internal and external factors which directed the different destinies of these subclasses of fishes.

During the Silurian the aridity was more intense than in Upper Devonian times. The elasmobranchs then, however, were yet too small and feeble to escape from the unfavorable environments of the land by taking possession of the sea. They must have suffered a severe repression, living chiefly in the limited permanent areas of fresh or brackish waters, unable to establish themselves in the open sea, even if some few did press away living or float away dead from the margin of the land. In the land waters, subjected to strong seasonal drying, a severe pressure of environment must have favored those fishes able to make a supplemental use of air. It would seem that at this time the earliest of ganoids probably arose, distinguished from their elasmobranch ancestors by the possession of a primitive air-bladder. As illustrated by the evolution of many groups, the development of a new order of animals apparently takes place in a limited region. They must become formidable and numerous before spreading widely. Thus, although the time of origin of ganoids was probably as far distant as the Silurian period of aridity, their period of initial expansion was deferred until the Middle Old Red Sandstone; their period of complete dominance within the land waters was deferred until they were favored by the climatic changes to higher aridity, which marked the closing epoch of the Devonian.

LIVING DIPNOANS AND CROSSOPTERYGIANS

A few lingering representatives of the dipnoans and crossopterygians still live in the fresh waters of the tropics. They throw valuable confirmatory light on the Devonian conditions of environment. These living relics of the past preserve, furthermore, to modern times the destructible tissues of Devonian fossils, and even, to a greater or less degree, those abstract summations of life—the habits by which the Devonian fishes met the conditions under which they lived. A review of these adaptations to environmental relations, as seen in the living representatives, will here be given.

The three existing genera of dipnoans or lung fishes show a wide distribution and marked adaptations to dry seasons and diminished waters.

Ceratodus, the Australian lung fish, is known to have existed as far back as the Triassic.[14] It lives readily in partially dried-up water-holes, foul with dead fishes of various kinds. It rises to the surface at irregular intervals to breathe air by means of its air-bladder, which functions as a lung. It is also dependent, however, on its gills, and soon dies when removed from the water unless kept moist. At present it is confined to the Mary and Burnett rivers of the eastern coast. This extremely limited distribution in Australia, with threatened extinction after such a prolonged and world-wide geological history, is presumably due to unfavorable conditions of environment, beginning with the development of zonal climates and accentuated now by its human enemies, owing to its large size, the fondness of the Australian natives for its flesh, and the ease with which it may be captured when confined to the shrunken water-holes.

Protopterus, the African genus, has a wide distribution within that continent, extending from the southern margin of the Sahara to the northern limits of the Kalahari, living thus under equatorial latitudes, in regions marked in large part by moderate precipitation, and practically throughout by alternations of seasonal rainfall and drought. Its favorite habitat is in the marshes in the vicinity of the rivers. In respiration it uses its double swim-bladder as a lung, supplementing the use of its gills. In the dry season the marshes dry up, the fish burrows into the ground and passes into a summer sleep, during which it is entirely dependent on its lungs for respiration and on its body fat and muscular tissues for food.

Lepidosiren, the South American genus, leads a somewhat similar life, inhabiting the wide-spreading swamps and marshes of the Chaco country and passing into a dormant state in the dry season.

In limb development Ceratodus appears to be quite comparable to its Devonian relatives, but those of the two other genera are long and slender. Ceratodus is a bottom-loving fish and frequently supports the anterior portion of the body on its pectoral fins. It is also able to push itself backward by means of its fins, indicating that an elbow-like joint is functional. It has also been observed to paddle forward, using alternate movements of the pectoral fins. It is not, however, so amphibian-like in its movements as *Protopterus,* which will "walk" forward, balancing itself on its paired fins.[15]

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[14] The living form is quite commonly distinguished from the Triassic genus as *Neoceratodus.*

[15] Bashford Dean: Notes on the living specimens of the Australian lung-fish, *Ceratodus forsteri,* in the Zoological Society's collection. Proc. Zool. Soc., London, vol. i, 1906, p. 176.

The members of the only two existing genera of crossopterygians, *Polypterus* and *Calamoichthys,* live in the rivers of tropical Africa in regions subjected to the usual tropical alternation of wet and dry seasons, but do not show any adaptation to a life out of the water or even an unusual capacity to use the air-bladder as a respiratory organ, though, according to Budgett, the air-bladder of Polypterus is an accessory respiratory organ rather than a hydrostatic organ.[16]

Observations on *Polypterus bichir* show that the pectoral fins are used for progression, but their primary function is to act as balances, and they exhibit the characteristic trembling movements so often seen in the balancing fins of teleosts. In captivity the fish often remains motionless for long periods of time at the bottom of the water, the anterior part of the body resting on the tips of the pectoral fins. The latter are much less elongated than the notable "fringed limbs" of certain Devonian forms—such, for example, as Holoptychius. The pelvic fins of Polypterus are still less developed, constituting nothing more than spines.

Calamoichthys, the other genus of living crossopterygians, is a very agile fish, but is snakelike in form, swimming like a snake, and its body fins are still more reduced. In these respects it is clearly degenerate.

In the opinion of most specialists, the crossopterygians occupy a central position among fishes. Remotely connected with the selachians on the one hand and more intimately connected with modern bony fishes on the other, they probably also represent the ancestral stock from which the stegocephalian amphibians and the dipnoans have had their origin. Although the group is regarded as ancestral to amphibians, it is to be noted that the lingering representatives are not by any means as amphibious in their habits as are the remaining dipnoans. Nevertheless both orders possess swim-bladders which are primarily lungs, connected with the œsophagus by a duct. The living crossopterygians show indeed a paired lung, though it is without internal sacculations. As seen in the living dipnoans, the inside of the swim-bladder is highly sacculated, increasing its respiratory value. In Ceratodus the lung is single, but in Protopterus and Lepidosiren the organ is double, large, and quite lunglike in character. It is seen that minor changes, such as could well exist within a single family, might show a much larger use of the lungs in the crossopterygians.

There is reason to believe that the modern representatives of both of these groups are degenerate in certain respects. This is a feature which often marks the lingering representatives of archaic types, no longer contesting for supremacy in the living world. Dollo, in fact, has shown

[16] Largely from G. W. Bridge: Fishes. The Cambridge Natural History Series, vol. vii.

reasons for believing that the modern dipnoans, more especially Protopterus and Lepidosiren, have been derived from their Devonian ancestors by a series of retrogressive changes, gradually approximating toward a final scaleless and limbless condition.[17] The eel-like form of Calamoichthys, one of the two living genera of crossopterygians, illustrates the same tendency.

It is notable that all the lingering representatives of these two Devonian groups of fishes which are found so abundantly in the Old Red Sandstone are essentially tropical and live in climates marked by the alternation of wet and dry seasons. It is for just such conditions that the possession of the power of supplemental breathing by means of rudimentary lungs adapts these types, and herein they have an advantage over the fishes in which the swim-bladder has become adapted to other uses. These living forms thus offer strong corroborative testimony to the geological evidence that the Old Red Sandstone was laid down chiefly as terrestrial river deposits in a warm climate marked by seasonal dryness. Under such environments, in widely separated parts of the earth, these relics of the remote past have persisted to the present.

ENVIRONMENT OF THE EARLY AMPHIBIANS

The earliest known evidence of amphibian life is the impression on a slab of sandstone from the uppermost Devonian of western Pennsylvania of one footprint in fair preservation and with it part of another of the same series. The tracks were found in 1896 by the late Professor Beecher, who presented the specimen to the Yale Museum and supplied the information in regard to its geological position. The animal which made the impressions was named by Marsh *Thinopus antiquus*. Marsh makes the following statements concerning it:

"These impressions are of much interest, both on account of their geological age and the size and character of the footprints themselves. The one best preserved is nearly four inches in length, two and a quarter in width, and was apparently made by a left hind foot. On the inner side in front of the heel, a portion of the margin is split off, and this may have contained the imprint of another toe. The other footprint was a short distance in front, but only the posterior portion is now preserved in the present specimen. It is probably the imprint of the fore foot.

. . . "The geological horizon is near the top of the Chemung, in the upper Devonian. In the same beds are ripple marks, mud cracks, and impressions of rain drops, indicating shallow water and shore deposits. Land plants are found in the same general horizon. Marine mollusks also occur, and one characteristic form (Nuculana) is preserved in the footprint slab." [18]

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[17] Sur la Phylogenie des Dipneustes. Bruxelles, 1895.

[18] O. C. Marsh: Amphibian footprints from the Devonian. Amer. Jour. Sci., vol. ii, fourth series, 1896, pp. 374, 375.

The Devonian is overlain by the Lower Carboniferous, represented in Nova Scotia and New Brunswick by the Horton Bluff series.

"This consists of hard sandstones and shales often calcareous, associated with conglomerate and grit, and in some places with highly bituminous shales. They contain underclays and thin coaly seams, remains of Plants, Fishes, and Entomostracans, and footprints of Batrachians, but no strictly marine remains." [19]

"No bones of Batrachians have as yet been found in these beds, but the footprints indicate the presence at the beginning of the Carboniferous Period, and before the deposition of the Lower Carboniferous limestones, of both large and small species similar to those of the coal formation." [20]

Sir William Logan discovered the first of these footprints in 1841, on a slab of dark-colored sandstone, glazed with fine clay on the surface. The two rows of footprints are about three inches apart, the distance between the impressions in a single row being three or four inches and the individual impressions about one inch in length.[21]

G. F. Matthew, in his classification of batrachian footprints, remarks that the toes are pointed, five on the hind foot and probably four on the fore foot.[22]

In *Hylopus hardingi*, discovered in the Carboniferous shales of Parrsboro, the great length of the stride, which is nearly five times the length of the foot and twice as much as the distance between the rows of tracks, apparently indicates that the animal stood as high on its legs as an ordinary mammal.[23]

Tracks of a larger type, called by Dawson *Sauropus antiquior*, were found at Parrsboro in a horizon which Dawson states is probably that of the Horton series. The footprint is about three and one-half inches wide and scarcely half as much in apparent length. It shows four subequal toes and an outer toe diverging from the others and showing indications of a short claw. The shortness of the impressions in this species gives them a digitigrade aspect.[24]

A further record of the existence of the Amphibia is found in the Mauch Chunk shales of Pennsylvania. This formation of red shales and sandstones, reaching a maximum thickness of as much as 3,000 feet, occupies the upper half of the Lower Carbiniferous, or Mississippian period. The first impression to be found was that of *Sauropus primævus,*

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[19] J. W. Dawson: Report on the fossil plants of the Lower Carboniferous and Millstone Grit formations of Canada. Geol. Survey of Canada, 1873, p. 5.

[20] J. W. Dawson: Trans. Roy. Soc. of London, vol. 173, 1882, p. 651.

[21] J. W. Dawson: Acadian geology, 3d ed., 1878, pp. 353-355.

[22] Trans. Roy. Soc. Canada, vol. ix, 1903, sec. iv, pp. 109-121.

[23] J. W. Dawson: Trans. Roy. Soc. of London, 1882, p. 653.

[24] J. W. Dawson: Ibid., p. 652.

discovered by Isaac Lea in 1849, near Pottsville, at about 700 feet (one-quarter of the thickness) from the top of the formation. The impressions, handlike in form, were made by an animal whose stride was 13 inches and the breadth between the outer edges of the footprints 8 inches. Not long after this the Geological Survey brought to light, about 1,500 feet lower in the formation, another species of footprints of much smaller dimensions, and soon afterward two other varieties.

In 1908 Branson collected in Virginia footprints belonging to four or five species from near the bottom of the Hinton formation. This is in the Upper Mississippian.[25]

Since 1908 Mr. Unger, of Pottsville, Pennsylvania, by careful searching of the sections of the Mauch Chunk, admirably exposed near there, has collected a number of slabs showing impressions of footprints, mostly of rather small size and delicately impressed.

These details show the character and continuity of the amphibian record from the earliest known occurrence at the close of the Devonian, through the Mississippian (Lower Carboniferous) period. In all cases they indicate a sustaining limb holding the body clear of the ground. The foot is primitive, and in the earliest known occurrence, Thinopus, it is possible that a stage is represented before the full development of digits. The feet, in general, show a capacity for either walking or swimming.

A striking feature of this early record of the amphibians is that it consists not of bones, but of footprints. In the Old Red Sandstone, in contrast, are horizons of abundant and well preserved fish fossils. During the time of deposition of the Upper Old Red Sandstone the amphibians must have been in existence, but they are not preserved with the fishes. Apparently, then, they did not at first live under those conditions which resulted in the preservation of the fossils of fishes. This suggests that they were not compelled to concentrate into pools by the seasonal droughts, or if so concentrated they did not die under those conditions. Neither did they apparently live as yet in the shallow lakes. What, then, was the nature of their environment?

The first amphibian bones are found in the Edinburgh coal measures of the Lower Carboniferous coal field of Scotland. There the oldest known skeletons, those of Loxomma and Pholidogaster, are approximately contemporaneous with the footprints of the non-coal-bearing Horton formation of Nova Scotia. But the Lower Carboniferous coal measures gave way again to the deposition of red shales and sandstones.

[25] E. B. Branson: Amphibian footprints from the Mississippian of Virginia. Jour. Geol., vol. xviii, 1910, pp. 356-358.

Here, with the change in the nature of the sediment, the record reverts again to one of footprints and not of bones.

The significance of this has been discussed by the writer in other papers.[26] The amphibian footprints and bones are found in terrestrial deposits. The footprint of Thinopus, it is true, was made in a muddy sand holding a small marine gasteropod, Nuculana. Here, on the outer margin of a delta, the sea had contributed to the material, but the associated strata show dominant delta conditions, and, in the wide oscillations of the strand-line characteristic of delta fronts, deposition under shore and river conditions alternate. In the Mauch Chunk shale of eastern Pennsylvania, on the contrary, there is no trace of the sea, and here the amphibian footprints were left in drying muds in the midst of a broad delta plain, far removed from permanent waters.

The red shales and sandstones are markedly barren of organic remains, yet footprints and plant impressions are present. The sediments were characteristically deposited under conditions where they were subjected to drying and atmospheric oxidation. The recurrent drying out implies a fall of level of the ground-water. Such changes in ground-water, through the induced circulation, favors solution of slightly soluble materials, such as the mineral matter of bones, in the zone above. Even large and resistant bones are speedily destroyed if alternately wet and dried in the presence of oxygen and seeping waters. Such conditions are present in the delta soils of seasonally arid climates, but not in wind-formed desert deposits nor in the swamps wherein organic matter accumulates. The wetter and cooler the climate the more favorable become the conditions for the spread of swamp conditions, resulting in the accumulation of coal and permitting also the preservation of animal fossils.

A nearly continuous record of continental floodplain deposits may be followed from the close of the Silurian to the close of the Paleozoic and discriminated from the synchronous marine formations. This record shows a recurrent and increasing diastrophic and climatic instability, dating from the beginning of the Devonian. The record of climatic oscillation is seen in the manner in which the dominantly gray to black deposits of the Middle Devonian in the Appalachian basin give place in the Upper Devonian to the gray to olive marine shales of the Chemung and the corresponding red shales of the terrestrial phase known as the Catskill, indicating a movement toward aridity, though not attaining actual desert conditions. Then, at the opening of the Mississippian, a swing of the climatic pendulum toward wetter and possibly cooler condi-

[26] In relation to the amphibia see "The origin and significance of the Mauch Chunk shale." Bull. Geol. Soc. Am., vol. 18, 1907, pp. 449-476; especially pp. 472-474.

tions resulted in the carbonaceous deposits of the Lower Mississippian. Following this came a change toward marked aridity, so that the flood-plain and playa deposits of the Upper Mississippian are marked by mud-cracked red shales, cross-bedded red sandstones, deposits of gypsum, and even of salt. Then another backward and farther swing of the pendulum brought in the conditions which permitted the accumulation of conglomerates, gray shales, and abundant coals of the Lower Pennsylvanian—the true Carboniferous. This was followed by climatic oscillations which led to the greatest of known glacial epochs and, in the Permian, the most intensely arid conditions known in earth history.

The nature of the geologic record of amphibians indicates that they evolved under climates marked by seasonal dryness and inhabited river plains far from the sea. The abruptness of appearance of well developed sustaining legs and feet points to an origin perhaps as far back as the Lower Devonian, but a rapid expansion and evolution in the Upper Devonian. They survived the change to more generally wet conditions in the Lower Mississippian, but showed more convincingly their adaptation to semi-arid continental conditions through the footprint record they have left in the Mauch Chunk shales. The impressions of plants indicate that over the broad river plains of eastern Pennsylvania there flourished each season an herbaceous vegetation of cryptogams following the withdrawal of the river floods, until the advancing seasonal dryness caused it to wither. No traces of an arboreal vegetation have been found, and this, taken in conjunction with other facts, suggests that in the dry season the streams completely vanished, or at least were reduced to rivulets and water-holes unable to afford sufficient underground water to support an arboreal vegetation on the banks.

The early amphibians therefore were not only adaptations from fluviatile fishes, but at first seem to have been restricted to uplands or to river plains, where the seasonal dryness was emphasized—conditions which prevented, however, the preservation of their bones. Doubtless less rapid swimmers than their ancestors and probably small in size at the time of their origin, the natural explanation of their absence from the more permanent floodplain waters would appear to be in the better adaptation of the more powerful fishes for these localities, the better adaptation of the amphibians for theirs, and a closeness of adaptation to environment which at first prevented the intermixing of the two faunas. It appears to have been but a short geological time, however, until the expansive evolution of the higher group, aided by widespread oscillations in climatic conditions, adapted them to a life in an environment suitable for

the preservation of their bones and brought them into competition with the piscine inhabitants of such regions.

Evaluation of Causes in the Rise of Amphibians

ACTION AND REACTION BETWEEN ENVIRONMENT AND ORGANISM

Organisms are hedged in on all sides by organic and inorganic bounds. This environment presses in on and tends to restrict more or less insistently the limits of action of the individual, forming a "pressure of environment" against which the species must exert itself to prevent extinction. There is here an equality between action and reaction. As long as a balance is maintained, the species holds its place unchanged. But time brings to pass either restriction, retrogression, or extinction of the species on the one hand or an expansion and evolution on the other. When such change occurs, is the ultimate cause to be found in modifications of the external world or of the internal nature of the organisms? Which is action and which the reaction, or is there an interaction requiring a concurrence of both external and internal causes in order to accomplish those great leaps which have occurred in the upward progress of evolution? The vertebrate paleontologist has most commonly studied the results without attempting to sift out the controlling cause. The biologist has come to place most weight on changes in the germ plasm; perhaps because the field of his observation does not include those changes in enveloping nature which mark the progress of geologic time. The geologic record shows that the transformations of faunas are profound and rapid in proportion to the greatness of the terrestrial changes in climate and geography. This correspondence indicates that the time of the greater evolutionary advances is determined by external causes. Through such environmental changes an intense struggle for existence is set up, the death rate rises high and eliminates less hardy and adaptable types. At such times the advanced mutations, if such can come to exist, have a relatively higher chance of survival than in less strenuous times, and are less likely to remain submerged within the common average of the species. Such are the general geological indications. Let attention be given, however, to individual factors.

ENEMIES OF THE WATERS, AN INOPERATIVE CAUSE

It has happened with many forms that when the pressure of enemies has become too great, this pressure has gradually forced them to some degree into a new environment and a new mode of life. Flying fish leap into the air. Beavers and muskrats dive to safety. Many rodents escape into trees or burrow into the earth. Could this pressure on fishes in their

native environment have been a cause competent to account for the passage to terrestrial life? The answer seems clear that it was not a true cause.

Such a pressure of environment has been always present, yet on lands free from enemies has not led to renewed adaptations among fishes. Those few which crawl on the land do not do so to escape their enemies. The carnivorous enemies of a group of animals can not cause extinction without the aid of other causes, unless those carnivores live also on other kinds of food; for when the numbers of the food animals become reduced the species ceases to form a sufficient food for the carnivorous foes. A balance is therefore struck between the large number of herbivores and a smaller number of their carnivorous foes. Furthermore, in the case of the amphibians, the young stages were still spent in the water. Where safety of environment is sought, it is especially in the breeding season that it becomes necessary. An even more conclusive argument against such an accusation of weakness concerning the first breathers of the air is found in the formidable teeth and head armor with which the first of amphibians were endowed. As soon as they appear under conditions where their bones could be preserved, they are clearly carnivores and the dominant creatures of their habitat.

FOOD OF THE LANDS, AN INADEQUATE CAUSE

The hypothesis that there was a pressure from enemies in the rear which forced the amphibians from the waters appears contrary to the evidence; but as the next step in the analysis of causes must be considered, the possible efficiency of unused foods on the lands as a bait or lure to draw the fish from the waters. The lands have supplied food presumably since at least early in the Paleozoic. At first low, cellular cryptogamous vegetation constituted the only organic covering, then vascular cryptogams, arachnids, and primitive insects appeared. The variety and quality of plant and insect foods have increased throughout the geologic ages. The temptation to avail themselves of such foods is ever before those marine animals which live in the tidal zone. To what degree have the animals followed up that temptation? A host of worms, mollusks, and crustaceans dwell there, yet when the receding tide leaves them stranded the worms and crustaceans burrow into mud or under stones to await the return of the waters. Many mollusks close their shells and certain small fishes burrow in sand or moss or in the chinks between stones.

Even on isolated lands where terrestrial enemies are absent there is shown but little tendency for marine animals to pass actively beyond the reach of the waters. The land crabs and the jumping-fish (*Periophthal-*

mus) are almost unique exceptions. The numerous examples of fishes, mostly tropical, which can remain active out of water are almost all fishes of fresh-water origin. Further, it is among the fresh-water fishes that the swim-bladder functions most commonly as a respiratory organ. The rarity of the passage of crustaceous, gasteropods, and vertebrates from a truly marine to a truly terrestrial mode of life through the apparently open path of the tidal zone adds to the evidence that an unused food supply could not alone operate as a cause sufficient to induce this change, for so far as this factor is concerned the river faunas would have no clear advantage over those of the tidal zone.

LURE OF ATMOSPHERIC OXYGEN, AN INEFFICIENT CAUSE

Viewed from the standpoint of animal activity rather than from that of body building, oxygen, taken into the blood through gills or lungs, is a food as essential as the fluid and solid substances, absorbed through the walls of the intestinal canal. The higher animals, as illustrated by birds and mammals, demonstrate by their warm-bloodedness and sustained activity the great advantages resulting from breathing oxygen directly from the air rather than indirectly abstracting it from solution in water. Further evidence in this direction is supplied by the many instances in which the descendants of land vertebrates have reverted to a life in the water. In no group, whether inhabiting fresh waters or marine, has there been a reversion to the use of gills or the equivalence of gills after the use of lungs had been definitely acquired. This is in contrast to the rapid reversion to fishlike forms, and in spite of the limitations to mode of life imposed by the necessity of returning to the water surface at frequent intervals to breathe.

Still more convincing in this regard is the independent acquisition in numerous instances among fishes of various devices for using air directly as an accessory means of respiration. It is among the fresh-water fishes, and more especially those of the tropics, that such adaptations are frequent and conspicuous. Examples may be cited from among teleosts of numerous species, belonging to a number of genera and several families, in which air is swallowed and passed along the alimentary canal. In other fishes complex surfaces, highly supplied with blood vessels, exist in chambers above the gills, in some instances as bony outgrowths from certain gill arches, in others as thickened and puckered surfaces of a superbranchial cavity. The commonest device, however, and that which is developed in the nearest allies to the amphibians, is the use of an air-bladder, which may be single or paired, as an accessory respiratory organ.

The question, then, naturally arises: Do not fishes tend to become air-

breathing merely from the advantages in oxidation, even if living permanently in the water, and would not such amphibious types tend in turn to abandon the use of gills and become solely lung breathers? Although such progress may appear natural, nevertheless a negative answer is indicated by the small direct use made of air for respiration by the marine pelagic fishes, even where these, notably as in flying fishes, live at the surface, are of active habit and come in frequent contact with the air. It is especially in fresh-water fishes that accessory respiratory organs are employed and their use is directly related to the varying impurity of the waters in which they live. It is thus an adaptation which has been forced repeatedly to a greater or less degree on fishes by the recurrence of an unfavorable environment rather than one assumed within a constant environment because of inherent advantages. The same conclusion is reached by an examination of the other phyla of marine organisms. Although many of them live at the surface of the water, or on bottoms so shallow that they can readily reach the surface, they have not acquired supplemental or substitute breathing organs which enable them to live permanently on the air. Many crustaceans can utilize air if their gills are kept moist with sea-water, but the use of air has not materially modified their respiratory apparatus or enabled them to readily abandon the sea.

It is probably true that in the Lower Paleozoic insects arose from trilobites and arachnids from merostomes. These advances for land life and atmospheric respiration are, however, like the development of lungs in vertebrates, almost unique in the phylum. The marine forms have not tended toward atmospheric respiration again and again in the way that they have tended to become modified to many forms adapted to life in various ways. The development of spiracles in insects involved as profound an organic transformation as that of the development of lungs and a four-chambered heart in the rise of air-breathing vertebrates. Among arachnids the organic change is less profound. Both classes may have attained the power of air-breathing from the habitat of the land waters. Their evolutionary histories, so far as known, are not at variance, therefore, with the argument derived from the vertebrates. The rise to air-breathing was not the result of the lure of atmospheric oxygen, but appears to have been an advance by compulsion, owing, it would seem, to oscillations in environment as measured by the varying content of dissolved oxygen in the land waters.

THE SWIM-BLADDER ORIGINALLY A RESPIRATORY ORGAN

The swim-bladder, or air-bladder, as it is variously called, appears to be now chiefly a hydrostatic or equilibrating organ. In some fishes,

however, it functions as a part of the auditory mechanism; in others it serves apparently as a closed reservoir for the storage of oxygen secreted from the blood. In certain large groups of fishes it is wholly absent; in others it is completely disconnected, except in the larval stage, with the œsophagus. It lies on the dorsal side of the intestinal canal. Only in a few forms is it clearly an accessory organ of respiration. Many zoologists have regarded its original purpose as not respiratory. Some—as, for example, J. A. Thomson—have stated that there is no demonstrable homology between lung and air-bladder.[27]

That the air-bladder was, however, originally an accessory breathing organ which has now largely lost its use seems conclusive when the evidence of paleontology is added to that of zoology. The argument is admirably stated by Charles Morris[28] and is adopted by Jordan.[29] The air-bladder is not an organ essential for swimming or equilibration, since it is completely absent in the selachians. It is also variable within the same genus, the mackerel having none, yet one exists in *Scomber pneumatophorus,* a species which in every other respect closely resembles the mackerel. It seems, therefore, to be an organ which, if originally necessary, has become now unnecessary for the original purpose, and has been retained through its various uses in secondary functions.

The nature of the original use of the air-bladder is indicated by two lines of evidence: First, in those fish which possess an air-bladder there is a pneumatic duct during the larval stage which connects the air-bladder with the œsophagus. This duct in most cases disappears as the fish develops. Second, the ganoids are the ancestors of the modern bony fishes, and in every living ganoid the air-bladder not only connects with the œsophagus, but acts as a supplemental respiratory organ. This attains its maximum utility in the dipnoans, an archaic offshoot from ganoids. In Polypterus the duct, as in amphibians and higher vertebrates, opens furthermore on the ventral side of the œsophagus.

Morris, following the prevailing conceptions, considers that such a use may have become of advantage to the Devonian ganoids, because they were driven out of the open sea by the selachians, monarchs of the seas. He argues that they were driven into bays, estuaries, shallow coastal waters, and ascended streams, dwelling in inland waters. In such waters, thick with sediment and perhaps poorly aerated, gill-breathing was rendered difficult and the plant and animal food of the land tempted to a further independence of the water.

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[27] J. A. Thomson: Outlines of zoology, 1899, p. 461.

[28] The origin of lungs, a chapter in evolution. American Naturalist, vol. xxvi, 1892, pp. 975-986.

[29] D. S. Jordan: A guide to the study of fishes, vol. i, 1905, pp. 98-106.

We have seen occasion in the present study, however, to reverse certain of these supposed causes. The fishes appear to have migrated not from the oceans to the rivers, but in the contrary direction, yet the ancient cyclostomes show no trace of an air-bladder, though many of them return to the fresh waters for breeding. It is doubtful if the selachians ever possessed this organ when in their fresh-water habitat, since they now preserve no remnant of it, even in a larval state. A small cæcum embedded in the dorsal wall of the œsophagus of certain sharks may possibly, however, be homologous. It is further seen that the mere lure of food outside of the normal habitat is hardly competent to transform the physiology of a dominant race which could already find adequate sustenance. For such a great organic change there would appear to be necessary a positive pressure tending to drive the race out of its old habitat, not merely an attraction—a mere negative pressure of environment. That driving pressure was apparently the compulsion of the inorganic environment, not the pressure from organic foes. This will appear more clearly under the consideration of the next topic.

ARTERIAL AND RESPIRATORY SYSTEMS OF FISHES AND AMPHIBIANS

In figure 1, A, is given a diagrammatic representation of the plan of the selachian circulation, the type from which has arisen that of all higher vertebrates. It is seen that all the blood is forced from the heart through the gills, where it is oxygenated and passes thence to the body. That supplying the brain is taken independently from the gills and passes over a proportionately greater gill surface than that destined for the remainder of the body. This system of circulation is simple, involving only a two-chambered heart, but is highly efficient, only oxygenated blood being sent to the body, only waste-laden blood returned to the heart. Its efficiency is measured by the power and sustained activity exhibited by many fishes and the rapidity of asphyxiation when they are removed from water.

In figure 1, B, is shown the circulatory system of Neoceratodus, the most primitive in its circulation of the few remaining dipnoans. It also represents a certain embryonic stage in the development of the amphibian circulation. It is seen that the air-bladder, functioning as a lung, receives blood from the last one only of the efferent gill arteries. If the auricle, ventricle, and conus arteriosus were of the same simplicity as in the selachian heart, this would mean that only a fraction of the blood would be sent to the lung after each passage through the heart. If the gills were not functional, the blood sent to the head and body would in that case be mostly unoxygenated. The system would be so inefficient

that an animal possessing it could not survive if compelled to abandon wholly the use of its gills.

This inefficiency is partly avoided by modifications which exist in Neoceratodus, but to a greater degree in the adult amphibian heart, as shown in figure 1, C, in which the gills have disappeared. In the salamanders a network of muscular strands with intervening spaces imper-

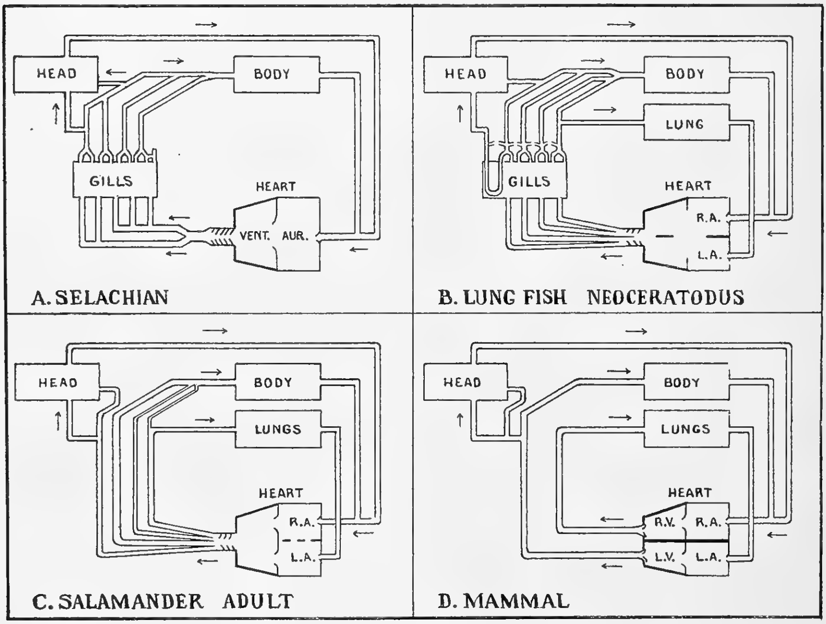


FIGURE 1.—*Diagrammatic Side View, respiratory-circulatory System of Vertebrates*

In the primitive plan, as shown by the selachian circulation, the blood enters the heart from the *sinus venosus;* thence it passes into the single *auricle.* This opens through a two-lipped valve into the single *ventricle.* From the ventricle the blood passes into the *conus arteriosus,* provided with rows of valves, and thence into the *ventral aorta.* This divides and then subdivides into five *afferent branchial arteries* on each side of the pharynx, the afferent vessels to the gills. From the gills the blood passes by means of four *efferent branchial arteries* on each side. From the first efferent vessel the *carotid* and *hyoidean arteries* draw their blood supply for the head. The four efferent branchial arteries unite into the *dorsal aorta,* whose branches supply the body. This is as much detail as the diagram shows.

fectly separates the single auricle of the fish-heart into a right and left auricle; the deoxygenated or impure blood from the body is received into the right side; the oxygenated or pure blood from the lung is received into the left. In the contraction of the heart the pure and impure blood are not separated by any wall in the ventricle and become more or less intermingled. The head, however, receives fairly pure blood, the body somewhat mixed blood, and the lungs mostly impure blood. In the frog

the development of the heart has proceeded farther and the two auricles are completely separated, but there is still but a single ventricle. In certain forms, as in Protopterus among dipnoans, there is a longitudinal median ridge on the walls of the ventricle and partitions in the conus arteriosus which serve further to guide the purer blood toward the head. Another device, present in many reptiles, is for the ventricle to contract in such a way as to assist in separating the two blood streams and driving in advance the purer blood toward the head.

Newly oxygenated blood should not, however, be sent to the liver before having its oxygen used by the body; blood from the intestines must, on the other hand, be sent to the liver. What, then, are the relations of the circulation of the blood leaving the air-bladder, and do they fit with the hypothesis that the original use of the air-bladder was as a supplemental breathing organ? In answer, it is found that among the higher fishes most of the veins from the air-bladder join the hepatic portal vein, but more or fewer of them, especially those from the dorsal wall of the organ, open into the posterior cardinals, and thus pass the blood directly into the heart. They may, as in Polypterus, even join the veins leaving the liver. In Neoceratodus the veins from the air-bladder unite to form a single vessel which opens as a separate vein into the left auricle. Thus, in the forms most primitive and making the largest use of the respiratory function, more of the blood is sent from the air-bladder directly to the heart and less to the liver.

Finally, in figure 1, D, is shown the completely efficient system of a four-chambered heart with its complete separation of the two blood streams, independently evolved in the two warm-blooded classes of vertebrates—birds and mammals. Crocodiles among reptiles have achieved the same plan, though the dorsal aorta receives blood from both ventricles and therefore still supplies mixed blood to the posterior parts of the body. This four-chambered heart is equivalent to two two-chambered hearts. Consequently in the development of air-breathing by means of lungs a second heart has had to be evolved and added to the original selachian system, but the development of the second has lagged long behind the rise of lungs. The essential similarity of the system independently attained in birds and mammals points to its necessity in that competition in life which demands sustained activity. By comparison the hearts of the lower air-breathing vertebrates are seen to show mere makeshift devices.

If it be sought to place the circulatory system of a lung-fish, such as Neoceratodus, in its evolutionary position between that of the selachian and that of the mammal, it is seen that in the retention of the gills it is

less than half way; in the development of lungs it is much more than half way; in the development of its heart it is at least half way. The gills could not be lost until the whole circulatory system of the selachian had been largely remodeled. The lung preceded this remodeling, and the changes in the heart were made necessary by the increasing disuse of gills. The lung-fish, then, does not show the initial beginnings of air-breathing, but rather that lowest state which could survive from the remote past to the present.

If a broad control by natural selection were not postulated as the governing cause, it would be necessary to assume that orthogenetic mutations went forward, first, in the development of lungs; second, in the development of a new type of heart, and, third, in the atrophy of gills; and that the first two changes, at least, although in different organs, were blindly working toward the same end, one not at that time established or even apparent in nature. This is too great a demand on fortuitous coincidence and not in accord with the law of probabilities. The pressure of natural selection, operating to a degree at which it threatened the very extinction of the entire race, is demanded to explain the guidance of development and transformation of unrelated organs into mutual support and combined efficiency in a new sphere of life.

PROBABLE ORIGIN OF THE AIR-BLADDER AS AN INTESTINAL DIVERTICULUM

If now we attempt to reconstruct the stages which led to the development of lungs, a preliminary survey must be made of the devices for using air which are employed by modern fishes under similar environmental conditions, but fishes whose air-bladder had been modified previously to other uses and who were therefore required to evolve new structures to meet this respiratory need. The data regarding accessory organs of respiration as found among teleosts are brought together by T. W. Bridge,[30] and the following are his statements:

"Accessory organs of respiration.—In certain Fishes of peculiar habits, or living under special external conditions, accessory respiratory organs are developed.

"Although in this particular instance no special organs are formed, mention may first be made of the singular method of intestinal respiration in vogue in some Teleosts. In one of the Loaches (*Misgurnus fossilis*), air is swallowed and passed along the alimentary canal until it is finally voided at the anus. The mucous membrane of the intestine is extremely vascular, and hence the blood comes into sufficiently intimate relations with the swallowed air to admit of it exchanging carbon dioxide for oxygen. Intestinal respiration also occurs in species of the South American fresh-water genera of Siluridæ and Loricariidæ, *Callichthys*, *Doras*, *Loricaria*, and *Plecostomus;* and in some cases

[30] Fishes, 1904, pp. 292-295. The Cambridge Natural Science Series.

the area of respiratory surface is considerably increased by the development of folds and processes of the intestinal mucous membrane.

"In a few tropical Teleosts curious labyrinthiform organs are developed in connection with certain of the branchial arches, and serve as accessory breathing organs. In the Indian 'Climbing Perch' (*Anabas scandens*), of the family Anabantidæ, the organ consists of three or more concentrically arranged bony laminæ, with wavy, crenulated margins, attached by a common bony base to the upper extremity of the fourth branchial arch, and enclosed in a special dorsal enlargement of the branchial cavity. The vascular membrane which invests the laminæ is abundantly supplied with venous blood by a branch of the fourth afferent branchial artery, the equivalent efferent vessel joining the dorsal aorta. Essentially similar organs are found in several genera of Osphromenidæ (e. g., *Polyacanthus*, *Osphromenus*, and *Trichogaster*). A simpler form of respiratory organ of somewhat the same type occurs in the Indian family Ophiocephalidæ. In these Fishes there is, on each side, an accessory branchial cavity, situated above that which contains the gills, but freely communicating with it. The cavity is lined by a thickened and puckered vascular membrane, but otherwise contains no special respiratory structures.

"In the Siluroid genera *Clarias* and *Heterobranchus* the accessory organ takes the form of branched, arborescent and highly vascular structures, developed as outgrowths from the dorsal extremities of one or two branchial arches, and enclosed within a posterior and dorsal expansion of the proper branchial cavity.

"Another example of these interesting structures occurs in *Chanos salmoneus* and a few other Clupeidæ in the shape of a coiled gill-like organ ('gill-helix'), which is supported by the dorsal segment of the fourth branchial arch, and enclosed in a similarly curved cæcal extension of the branchial cavity. Each 'gill-helix' derives its blood from the fourth afferent branchial artery, the corresponding efferent vessel joining the fourth efferent branchial artery. A similar spirally coiled 'gill-helix' is found also in *Heterotis ehrenbergii*, amongst the Osteoglossidæ, and in several species of Characinidæ.

"In other Teleosts the accessory breathing organ assumes the condition of paired lung-like outgrowths of the branchial cavity. Thus, in one of the Symbranchidæ, the Indian 'Cuchia Eel' (*Amphipnous cuchia*), there is a pair of small bladder-like sacs, with membranous and vascular walls, each of which opens into the branchial cavity above the first gill-cleft, and is supplied with blood by the afferent branchial artery of the gill-less first branchial arch. An extreme modification in the same direction is presented by the Indian Siluroid *Saccobranchus*. In this Fish a long cæcal diverticulum of the branchial cavity extends backwards on each side from the dorsal region of the first branchial cleft to the tail, and in its course is situated internally to the lateral trunk musculature, and close to the vertebral column. The walls of the cæca are vascular, but no special respiratory structures are developed within their cavities, which, during life, only contain air. In *S. singio* the right cæcum is supplied with blood by an extension backwards of the dorsal portion of the first afferent branchial artery of that side; the left, on the contrary, being supplied by the corresponding portion of the fourth afferent artery of the same side. In *S. fossilis* both air-sacs are supplied by the fourth afferent branchial artery. The efferent vessels join the fourth efferent branchial artery, right or left, as the case may be.

"With perhaps one or two exceptions, the accessory respiratory organs of Fishes seem to exist for the purpose of enabling their possessors to breathe in air. This is certainly the case with the labyrinthiform organs of *Anabas* and its allies, and also in such Fishes as *Amphipnous*, *Saccobranchus*, and the Ophiocephalidæ, and probably in others. Nearly all these Fishes are tropical in geographical distribution, more or less amphibious in their habits, and usually possess a remarkable capacity for sustaining life out of water, under conditions which are promptly fatal to ordinary Fishes. Thus, *Anabas scandens* may be kept alive for days in earthen pots without water, and when free is able to travel short distances on land, especially in the early morning when the dew is on the ground, while *Amphipnous* frequents marshes, lurking in holes in the grass and about the sides of ponds. In fact, even when in the water, access to air, which is probably swallowed and passed over their accessory breathing organs, is indispensable to their existence. Experiments conclusively prove that if the Fish is artificially prevented from obtaining air in this way asphyxiation speedily ensues.

"In addition to breathing air through the agency of special organs evolved for the purpose, there are many fresh-water Fishes which, like those just mentioned, periodically rise to the surface and swallow air in order to saturate the water which bathes the gills with oxygen."

There is seen to be a great variety in the methods of attaining accessory organs of respiration. Suppose that the conditions of life should change, such that the descendants of these fishes should have to rely wholly on a mode of respiration which was originally merely accessory. Those forms in which the respiratory organ is developed in the gill chamber, but only in connection with the fourth gill arch, would have to undergo some degree of reorganization in the arterial connections of the accessory organ, since the blood supply of the head is derived from the first two gill arches. A reorganization which would connect the accessory breathing organs with all of the afferent and efferent gill arteries would be relatively simple, however, by virtue of the law of repetition of structures as well as the readiness with which cross-circuits are built up between closely associated blood vessels. The readiness of such variation is exhibited in the genus Saccobranchus. In *S. singio* it has been noted that the right and left respiratory sacs are supplied with blood from the first and fourth afferent arteries respectively, whereas in *S. fossilis* both air sacs are supplied by the fourth afferent arteries. The efficiency of the originally supplemental apparatus as a substitute organ for oxygenation would be most easily attained in such forms as *Amphipnous cuchia,* where the air sacs are supplied by blood from the first afferent artery on each side; but efficiency would appear to be almost as readily attainable in other forms which use the pharyngeal chamber as the seat of the accessory organs.

Substitution of lungs for gills, following on this general method of accessory respiration, would not necessitate a reorganization of the heart and arterial system. A single ventricle could still drive wholly impure blood to the oxygenating organs; thence the efferent arteries would carry only pure blood to the head, and a dorsal aorta would carry only pure blood to the body. Collected into the venous system, only impure blood would be sent to the heart. The heart would remain two-chambered and efficient during and after the substitution of air for water as the medium of respiration. It would be necessary, however, for the forward part of the gill chamber to be utilized in order that pure blood should be sent to the head.

A distinctly different method of supplemental oxygenation is that of swallowing air and using the alimentary canal for the purpose of absorbing the oxygen. In this method, if the accessory mode of respiration should become the principal mode, a reorganization of the circulatory system would become necessary. This is because blood is taken to the stomach and intestines of fishes by the single cœliac artery, given off from the dorsal aorta behind the pair of subclavial arteries. Consequently, from the standpoint of the circulation system, the œsophagus and intestines are parts of the body, which come to function as the respiratory organ, as distinct from the pharyngeal or original respiratory region. The respiratory mechanism is no longer situated between the two-chambered heart and the body. As a result pure blood from the lungs would be mingled with impure blood from the body before entering the heart. This mixed stream would thence be sent back again both to body and lungs.

Which of these general methods of development of the accessory organs of respiration was pursued by the ancestors of Devonian ganoids? A probable answer may be derived by the study, on the one hand, of the circulation of those fishes which never made large use of air, and, on the other hand, by the study of the surviving dipnoans and crossopterygians and the descendants of the latter—the amphibians.

In most of higher fishes, Teleostomi, the air-bladder is supplied with blood by branches of the cœliac artery, with the addition of small branches arising directly from the dorsal aorta. In the dipnoan Protopterus a more anterior origin exists, in that the pulmonary arteries arise from the two dorsal aortæ between the place where these trunk arteries of the neck receive the fourth efferent arteries and the place where they unite into the single dorsal aorta. In Polypterus and in Neoceratodus, however, the arteries for the air-bladder are derived, as shown in figure 1, B, from a branch of the last or fourth pair of efferent branchial vessels. The pul-

monary arteries consequently originate anterior to the two dorsal aortæ. This is true also of the amphibians.

Thus considerable variation in the place of origin of the pulmonary artery is exhibited, but it is in closest relation to the arterial system of the stomach and intestines in those fishes, to whom in their evolutionary history air-breathing by means of the air-bladder has never been more than a secondary mode of oxygenation. The most forward connection is found in the amphibians, but even here the pulmonary artery is a *branch* from the fourth efferent artery and not in any sense an organ *between* the body and the gills.

Another line of evidence is found in the embryonic development of the air-bladder. In all those fishes which have an air-bladder it opens, during the larval stage, by means of a duct into the œsophagus distinctly lower than the pharyngeal cavity and in some cases near the stomach. In the dipnoans and ganoids this duct is permanently retained and serves as a respiratory passage. The development of the air-bladder shows thus a relationship to the œsophagus and not to the gill arches.

From these lines of evidence it is to be inferred that the reorganization of the heart and arterial systems which has had to take place to produce the efficient circulatory and respiratory systems of birds and mammals out of the two-chambered heart and gill-respiration of the primitive selachian was necessitated by the original location of the accessory respiratory surface as the forward part of the intestinal canal.

Originally was the air used for oxygenation swallowed, or was it expelled from the mouth or gills? It appears probable from the œsophageal connection that it was originally swallowed, but on the development of a larger respiratory surface, with the necessity for a rapid renewal of the air within the respiratory organs, the line of least resistance became that of a forward expulsion, a rhythmic regurgitation.

Even in those modern fishes which breathe air by means of accessory organs in the pharyngeal chamber the gills are probably not the typical channels for exhalation. It would appear reasonable, however, that if such fishes came to rely more largely on air, some, at least, might adopt the habit of inhalation through the mouth, exhalation through the gill openings. Rhythmic movements in the gill covers similar to those in lampreys, which are attached by their mouths, would apparently, in fishes coming to breathe by a pharyngeal chamber, be a quite possible and a most efficient means of maintaining respiration. The gill openings in that case would remain permanent features of the anatomy of the resultant air-breathing animals. Expulsion of air forward from the œsophagus would, on the contrary, naturally find its exit through the mouth or nos-

trils; the gill openings would become useless and retrogress to a temporary embryonic feature.

The absence of gill openings in air-breathing vertebrates, after the early embryonic stages, although it thus has interesting suggestions, can not be used, however, as a conclusive argument concerning the original location of the accessory organs of respiration, since this being once adopted, the other possible lines of evolution have not had opportunity to be demonstrated by nature. This particular point is only of interest, therefore, in consideration of what might have been, but never did come to be.

Let us turn back to the conclusions which may be drawn from the preceding lines of evidence bearing on the actual evolution of lungs. The several arguments point backward, like convergent finger-boards, to an early stage which has no living representatives; but we may draw a sketch from these converging probabilities. They indicate in the earliest ganoid fishes, possibly in Silurian time, an initial habit of swallowing air as a supplemental aid to respiration, necessary whenever the land waters became subnormal in dissolved oxygen. This habit grew with exaggeration of these environmental conditions and with increasing organic efficiency in this direct absorption of oxygen. The upper part of the intestinal canal would, in swallowing, have first contact with the air; would take out most of the oxygen and become specialized for this purpose. By the localization of respiration over this part of the canal, the necessity would be avoided of the oxygenated blood passing into the intestinal veins with the absorbed food products and thence to the liver. Greater need of respiration would lead to enlargement of the surface, resulting in the development of a sacculated diverticulum from the œsophagus. Muscular control would follow, permitting the rhythmic intake and expulsion of air. It would now no longer need to pass through the intestine, but would more readily be regurgitated through the mouth.

When the supplemental use of air became more important than water-breathing and at last became imperative, fundamental changes would have to take place in order that somewhat more impure blood should be sent to the lungs and somewhat less impure blood should be sent to the head and body. These changes would have to be simultaneous throughout the circulatory system and require that the arterial connection of the lungs must be shifted forward from the cœliac artery, and that a separate vein must pass directly from the lungs to the heart; the heart also must be modified so as to keep the two blood streams, that from the body and that from the lungs, to some degree separate. This degree of advancement, like other beginnings, must have been slow in attainment,

but it had to be reached in those ganoid fishes which, by virtue of their power to use air, have been able to occupy a special habitat and survive through the long ages which have elapsed since the Devonian. From this stage forward the existing relics from the past show the slow progress of that profound and fundamental further respiratory-circulatory transformation which has been necessary to permit the advancement of vertebrates from the lowly amphibian to the active and intelligent mammal.

COMPULSION OF SEASONAL DRYNESS

Thus an intestinal method of using air for supplemental respiration which initially had no clear advantage over another possible method, that by means of the pharyngeal chamber, but later had a disadvantage, was assumed through fortuitous choice and fixed by habit. It represented a parting of the ways. This blind choice of the ganoid fishes, directed by minor and unessential factors, fixed for all time the lines of evolution of vertebrates in regard to the fundamental life activities of respiration and circulation.

If lungs had been developed in the pharyngeal chamber and the use of air had thus involved no general upsetting of the circulatory system, then, irrespective of the compulsion of seasonal dryness, it is conceivable that a transition might readily have occurred to a larger use of air. Such a transition would have involved an increase of efficiency throughout the change. Once started it could have been carried forward merely from such an evolutionary momentum as has been called orthogenesis.

With that method of air-breathing which was adopted, however, the growing disuse of the gills resulted in a decrease instead of an increase in the efficiency of the organism. What had served very well as a supplemental organ became very inefficient as a substitute organ. To adapt it to sole use and still permit the animal to live, profound changes became necessary in the heart and its connections with the lungs. This remaking of the circulatory system as a result of the throwing of the burden of respiration on the rudimentary lungs is a measure of the compulsion of nature. The fish which had to make larger use of air instead of water was not as well off as the fish which in another region could still breathe only water, provided that the water was well aerated. Such a makeshift apparently could have been possible only where aerated water was not available in the environment. If, further, the fishes had been able to retreat from the seasonally untoward conditions, this would have been easier than the organic transformation. But if the fishes were trapped in rivers which in the dry season shrunk to crowded pools and in lakes which recurrently were reduced to slimy mud flats or even dried

out, then the ability to breathe air would be an advantage, enabling the possessors of that power, although gasping for breath and half asphyxiated, to live where other fishes died in masses. A long period of strenuous evolution is implied, the pressure of natural selection eliminating continually those not able to survive. Such internal changes of body plan, involving an initial inefficiency of function, require an external compulsion. The nature of that external force is found in the habitat of the Devonian ganoids and the compulsion of seasonal dryness.

Consequences imposed by Ganoid Fishes on subsequent Evolution

ULTIMATE CONSEQUENCES OF TYPES OF STRUCTURE

In the progress of evolution during the course of geologic ages many paths have opened up. The hosts of living things have spread out and occupied all to which they could become adapted. Each path has determined to a greater or less degree the subsequent journey of the race which starts on its course, but, like a labyrinth, the end could not be seen from the beginning. Many a wide and easy road has led to no further progress; many a promising way has ended in extinction; a few paths, narrow in their beginnings, have led by devious and difficult ascents to higher planes of life.

For illustration, if a reflecting intellect could have looked on the world at the opening of the Paleozoic; to it the exoskeleton of the arthropods would have seemed a happy combination, suited both for protective armor, weapons, and a muscular framework, marking apparently that phylum as the one to contain the rulers of the earth through all future time. During the Cambrian the animals possessing this organic plan were, in fact, the dominant life of the seas. But time made evident a fatal limitation; the exoskeleton was a non-living secretion and therefore could not grow. Frequent moulting was necessary with its exhausting struggle out of the old shell, the rapid growth before the new should harden, the helplessness of the soft-shelled stage. These conditions imposed the necessity of limiting the number of moults and keeping the body small. An escape from the dangers inherent in moulting was found in the development of metamorphosis; but this organic transformation precluded a continuity of experience during growth. Without such continuity there could not be teachableness. The completed insect must be an automaton, actuated from the beginning by the blind impulses of instinct.

In chordates, however, the decreasing emphasis on protective armor and the development of a living endoskeleton permitted them in time to

grow great in body as compared to the invertebrates and teachable from the gradual accumulation of experience. Seeing, then, how an organic plan may have ultimately profound results not yet in evidence in the actions and reactions which determined its beginning, what were the consequences imposed by the Silurian-Devonian ganoid fishes on subsequent evolution? In the adaptations recurrently necessary at that time for crawling and breathing, in order that river fishes could maintain their existence, what other methods, built up with slightly different habits, would have been equally efficient, but which, so far as we can tell, might have resulted in a lower, or possibly in a higher, future for vertebrates? This is not an idle question, evoked only as a speculative fancy, since a discussion of it gives a better insight into the causes and results of the plan which was pursued.

RELATIONS OF HABIT IN PRIMITIVE FISHES TO THE DEVELOPMENT OF PAIRED FINS

In regard to the mode of locomotion, crawling is effectively done by a snake-like or eel-like wriggling motion. This is a body form to which several of the surviving archaic fishes have in fact approximated. But the degeneracy of limbs which this mode of motion involves clearly cuts off such animals as tend to pursue it from further participation in progressive evolution. The ancestors of amphibians were therefore fishes with rather short, fishlike bodies and powerful paired fins.

The early ganoids and dipnoans were provided with two pairs of lateral fins, pectoral and pelvic. From these, although the stages have not been found in the record of fossils, the four limbs were evolved, and thus the number of limbs rests ultimately on the mode of swimming which called for the existence of these four fins supplemental to caudal propulsion. Modifications of habit in the ancestors of these fishes could conceivably, however, have given to them and to their descendants, the amphibians, either two, four, or six lateral appendages. What habits related to what environments favored the establishment of the number of limbs as four?

The bottom-living animals, such as illustrated by the eurypterids and ostracoderms, find a powerful forward pair of limbs, acting as oars on the bottom mud, sufficient for their needs. The origin of land-dwelling vertebrates from such forms would have been a heavy ultimate handicap on vertebrate evolution. The swimming types of fishes, on the contrary, have customarily retained the four lateral fins. In the archaic types, with an external primitive limb or archipterygium, the two pairs would seem to have been effective for the multiple function of guiding in swimming, and also rowing, or crawling through submerged vegetation. The

body form of the early crossopterygians, which, like other fishes, possessed lateral flexibility, but vertical rigidity, obviated the need of more than four such appendages for guidance or body support, as contrasted to the numerous appendages needed to support the vertically flexible body of arthropods. It was the habit of active river fishes, then, which determined the quadrupedal nature of land vertebrates. A closer study of the relations of habits and environment of river fishes to the use of fins would be instructive toward restoring this stage in the geological history of vertebrates with more certainty than can now be done.

Two pairs of lateral fins were sufficient to meet the demands of the Silurian and Devonian environment. It is a suggestive question, however, if the development of habits leading to six initial limbs would not have been an ultimate advantage. The insects rising from a many-legged stock have permanently retained six as the minimum advantageous number with the exception of certain butterflies in which the forward pair has become vestigial. With six limbs in the vertebrate body-plan, four might have been retained for body support and purposes of locomotion, and two could have been diverted readily and in many instances for other uses, especially able, as arms and hands, to serve the higher needs of the organism and stimulate the mental development. Such a stimulation and wider competition would have tended apparently to introduce the mental factor as of importance at an earlier era in evolution.

There was a time in vertebrate evolution when perhaps six limbs were still a possibility. The acanthodean sharks show a lateral line of spines between the pectoral and pelvic fin spines. The Proselachii, as seen in Cladoselache, show traces of a lateral fin fold. Specialization in the early elasmobranchs, however, reduced these possibilities of multiple limbs to the limited number of four. What habits in the ancestral chordate paralleled the development of four rather than of two or six primitive limbs? To sum up the preceding discussion, the answer would seem to be a habit of vigorous swimming, but close to the bottom, developed in connection with caudal propulsion. This habit was developed in connection with the possession of a notochordal axis between the alimentary and neural canals, a body plan tending to vertical stiffness, but lateral flexibility. The passage of the four lateral fins into the fringed fins of the early crossopterygians, taken into connection with the knowledge of their fluviatile habitats in semi-arid climates, was apparently due to life in shallow river waters. In the time of flood these spread widely over the river plains. In such shallow floodplain and swamp waters much tangled vegetation grows, and the fins, to aid in the progress of the animal by subaqueous crawling through this vegetation, became elongated as fringed limbs.

After supplemental oxygenation by air-breathing had become established as a necessity of the climate, the possibility arose of continued activity during the season of shrinking waters, and this required that the fringed limb, suited for subaqueous crawling, as well as guidance in swimming, should now become modified and strengthened for subaerial crawling, involving, as it does, the partial support of the body, but losing very largely its original swimming function.

POSSIBLE CONSEQUENCES OF ANOTHER MODE OF SUPPLEMENTAL RESPIRATION

In regard to the mode of supplemental use of air by means of an air-bladder which became established among the early ganoid fishes, the fact that this was but one of several possible modes is shown among certain modern fishes by the actual employment of various other devices. Slightly different habits in meeting slightly different conditions, adventitious and inconsequential, so far as the immediate needs were concerned, would have directed the Silurian-Devonian fishes into other modes of using air and might have readily shunted onto another track the whole subsequent course of vertebrate evolution.

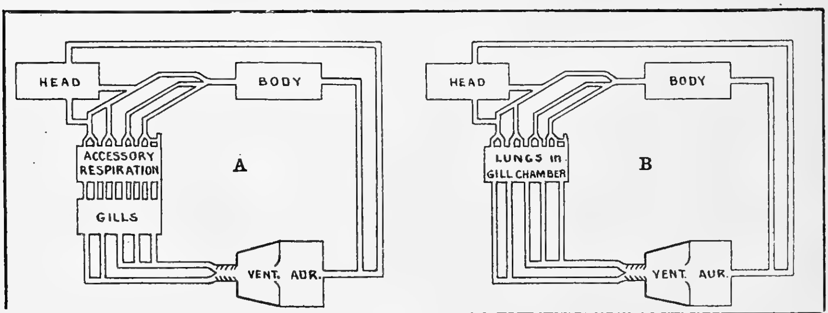


FIGURE 2.—*Diagrams illustrating a possible Mode of Evolution of Air-breathing*

A. Accessory breathing organs as they might have been developed in the gill chamber.
B. Resultant simplified circulation of air-breathers which would have resulted.

In figure 2 is shown what might have been the result if the first fishes which began to use air had developed within the gill chamber, in connection with several gill arches, labyrinthiform or arborescent growths for the utilization of air. No alteration of the heart and circulatory system would have been required. A mere increase in size of the respiratory organs and of strength in the heart would have provided the mechanism for warm-bloodedness and more sustained bodily activity. Contrast this possibility of rapid evolution with the long geologic ages which passed

before the acquisition of the four-chambered heart and the separate pulmonary circulation. During this time it was impossible for the air-breathing vertebrates, especially those of smaller size, to remain active except in warm environments. Such sustained activity, furthermore, as is needed for the present keenness of competition between herbivores and carnivores, or as is necessary for the flight of birds, was impossible.

But warm-bloodedness and the possibility of continued bodily activity carry with them a far-reaching train of consequences. Hair and feathers come to form a body covering to hold in the body warmth; the range and quantity of animal life has been thereby enormously extended over the globe. Cold, which in the Permian must have greatly restricted the life of reptiles, in the Pleistocene served as a stimulus to the growth and activity of mammals.

But the nervous system, and especially the brain, are the parts of the body which stand in most need of pure blood. This is shown not only by those elaborate makeshifts in amphibians and reptiles by means of which purer blood is sent to the head than is sent to the body, but experiment shows that a temporary deficiency of oxygen, as in poisoning by illuminating gas, destroys consciousness and even does more or less permanent damage to the brain, when other organs are but little affected. Furthermore, there is a correlation between mind and body; so that mental and bodily activity are associated. Mere mental activity should not, however, be confused with intellectuality. Birds, for example, show, as a class, great mental activity, but it is dominantly reflex and emotional rather than judicial and intellectual.

The Age of Reptiles was a long era dominated by small and stupid brains in great and armored bodies. Since mind was lacking, the first wave of terrestrial evolution had to put all its stress on mere size and bodily power. With the rise of a perfected circulation the emphasis of evolution became transferred to advances in mental and bodily activity. When, at the end of the Mesozoic, the world-changes modified the older environments, the overspecialized reptiles disappeared and the animals possessing these more efficient processes could take advantage of the new conditions. Then it was that the Age of Mammals dawned. This is a turning point in evolution, for with the radiative expansion of warm-blooded land vertebrates there began a remarkable development of the brain, as shown by the increasing ratio of brain weight to body weight. Through the Tertiary this ratio doubled and redoubled, in geometrical progression, in those leading mammalian orders whose evolution has been traced. The mental factor in connection with a perfected circulation had at last reached a primary importance prophetic of the Age of Mind.

Passing back to the hypothetical consequences of another method of evolving air-breathing, if there had been a highly efficient respiratory-circulatory system in existence from the beginnings of air-breathing in the Silurian and Devonian, the development of mentality would then have received a great stimulus. The whole subsequent career of land vertebrates would have been altered. The actual results are from such a complex interaction of external and internal changes that the exact consequences of such a postulate can not be predicted. It would seem well within the limits of possibility, however, for that first era of stupidity, bulk, and blind ferocity to have already reached its culmination and met its fate in that world revolution which closed the Paleozoic. It is possible that an era of warm-bloodedness and its train of consequences would have begun in the early Mesozoic instead of waiting for long geologic ages, waiting on the slow perfecting of the reorganized circulatory system. If, in addition, a more rapidly evolving brain had been able in air-breathing vertebrates to utilize more generally a forward pair of limbs to serve the mind, it is seen how widely different the history of land vertebrates might have been.

CONCLUSION ON THE DANGERS WHICH HAVE THREATENED ORGANIC PROGRESS

But there is another side, not so pessimistic, supplemental to this picture of what might have been. So far as evolutionary history has been interpreted, there is found no indication that low and isolated lands with monotonous history, such as illustrated best by Australia in later geologic times, would ever have carried evolution forward to its fruition in intellectual life. Yet in the earlier Paleozoic ages the northern lands, flooded by shallow seas, were often of this character. Contrast with this geological monotony, which once seemed likely to endure without end, the expansion and diversification of the land surfaces through later geologic times, that oscillation of conditions which is seen to have stimulated progress.

Or, again, one vast and monotonous land surface, such as is seen on the planet Mars, is not regarded as an environment well adapted to stimulate marked advances in evolution. The waves of progress have required first restriction and isolation with wide variations of conditions, so that unlike faunas could be produced and the better types acquire dominance within a limited habitat. Second is required the migration, mingling, and competition of faunas. Judged by these principles, the post-Silurian history of the northern hemisphere is seen to have been increasingly favorable for the evolution of the higher types of land life. But that

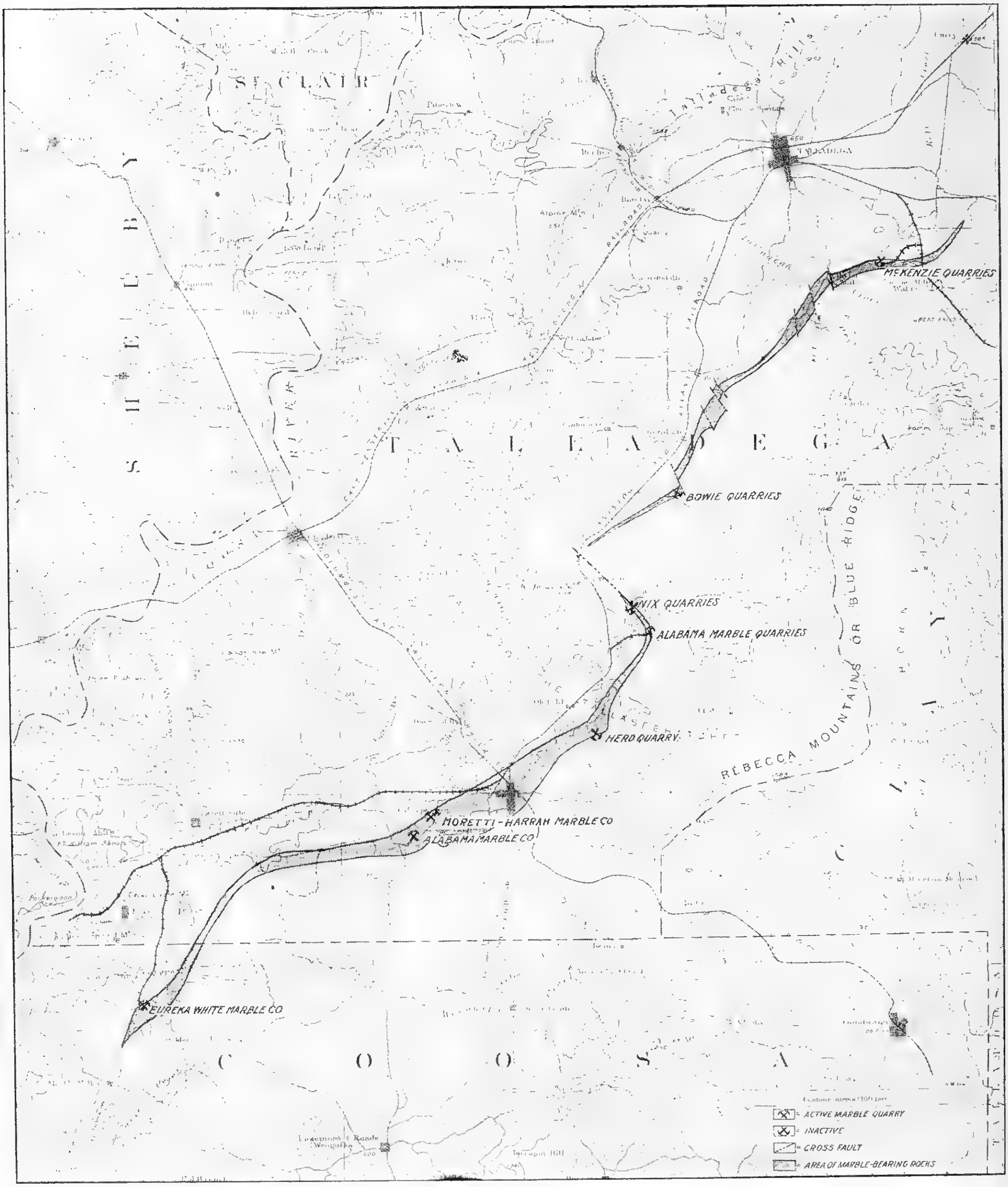
this should have been the sequence of the physical events of earth history has depended on obscure conditions in the earth's interior, which appear to have no close correspondence in the two celestial bodies whose surfaces we are able to study—the moon and Mars. The progress of life on the earth has been highly favored, consequently, by the rhythmic pulses of climatic and diastrophic changes which have remorselessly urged forward the troop of living creatures. The progress of organic evolution has depended on a series of fortunate physical events, conditioned in the internal nature of sun and earth, rather than dependent on mere life activities as expressed in orthogenesis through long periods of time. Evolution is in no sense an inevitable consequence of life.

Beyond the peculiarly terrestrial pulsatory forces which have stimulated evolution we must keep in the background of the mental vision, furthermore, the fact that the earth had to fulfill certain basal conditions before land life was even possible. To illustrate: the ocean basins exist only by virtue of the fact that certain greater segments of the crust are denser than others, and that in addition a condition of vertical equilibrium prevails for these large segments. Except for these two conditions which determine the existence of ocean basins, a nearly universal ocean would prevail, the lands being reduced to new-born mountain ranges or to volcanic islands.

Continents permanently too wide and high, on the other hand, would be without sufficient rain, or by accelerating erosion would tend to reduce the content of carbon dioxide below that minimum necessary for a vigorous growth of plants. Or, if the land surfaces were largely of basaltic rocks, as they were in the earliest known periods of earth history, the content of atmospheric oxygen, so necessary for the activity of the higher life, would be very greatly reduced through oxidation of the high content of ferrous iron and sulphur which these rocks contain.

These are examples of the many dangers which have beset the progress of life. Happy was the outcome, in that none of these dangers which loomed across the geologic ages were in reality complete barriers to further progress of the stream of living things. When the difficulties were encountered, there was often a variety of ways by which they could be met. The choices of the ways depended frequently on adventitious and minor causes. The very fact that at many times various organic responses were possible precludes the view that every time the initial advance, while serving the immediate ends, was also the best as measured by the ultimate requirements. Another choice, at the very beginning of our air-breathing life, so far as we can crudely estimate the results, would appear to have made possible a more rapid and competitive advance.

Yet man, while appreciating these apparent imperfections in evolution, should rejoice that the earth has had such a fortunate planetary history, and that the choices made by remote ancestral forms in response to the pressure of new, and to them adverse, physical conditions, were not at any time disastrous in their limitations or did not lead to a too long deferment of the attainment of intellectuality—the rarest fruit of time.



LOCATION MAP OF CRYSTALLINE MARBLES OF ALABAMA

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CRYSTALLINE MARBLES OF ALABAMA [1]

BY WILLIAM F. PROUTY

(Presented before the Society by title only December 29, 1915)

CONTENTS

VARIETIES OF MARBLE OTHER THAN CRYSTALLINE IN THE STATE

There are several varieties of marble in the State of Alabama, both crystalline and semi-crystalline. The chief semi-crystalline marbles comprise the variegated and somewhat brecciated deposits of Middle Cambrian age in Shelby County, near Calera;[2] the gray and somewhat variegated marble, chiefly of Pelham age, at Pratts Ferry, Bibb County,[3] and the local deposits of marbelized Subcarboniferous and Knox limestones in the northern part of the State. Of these the Pratts Ferry deposit alone has been in the past considerably developed.

[1] Published with the permission of the Alabama Geological Survey.
Manuscript received by the Secretary of the Society April 7, 1916.

[2] Henry McCalley: The valley regions of Alabama, vol. ii, pp. 513-514.
Charles Butts: Bull. U. S. Geological Survey, No. 470, pp. 237-239.

[3] Henry McCalley: The valley regions of Alabama, vol. ii, pp. 498-499.
P. Byrne: Marble formations of the Cahaba River in Alabama. Trans. Engineering Association of the South, vol. xii, pp. 48-59.

The crystalline Marble

GENERAL EXTENT AND LOCATION

The crystalline marbles of the State are the only ones which are now being quarried. They are located in a long and narrow area extending through Talladega County and into the northern portion of Coosa County—a distance of approximately 35 miles in a northeast and southwest direction (see map showing location of marble beds). The maximum width of this area, which includes the marble-bearing rocks, is a little less than 1½ miles. Both extremities of the field are terminated by converging faults.

GENERAL GEOLOGIC AND TOPOGRAPHIC SETTING AND AGE

The marble area is for its entire length on the western border of the Talladega phyllite (Ocoee), from which it is separated, for the most part at least, by a reverse fault. For much of the distance on the northwest side of the marble area are found the deep red lands of the Knox Dolomite formation. Phyllites, whose age in some cases is Cambrian, occur locally on the northwest side similar in character to those on the southeast side of the marble.

The long, narrow area in which the marble occurs is in part a fault-block. The strike of its rocks is in many places different from that of the bordering areas.

While there is no direct fossil evidence as to the age of the marble in any part of the field, the general thickness and the character of the associated rocks lead to the conclusion that the age varies in different parts of the field from Pelham (Chickamauga) through Beekmantown to Middle Cambrian.

The thickest deposits of marble are to be found toward the central and southwestern part of the field, where at the present time the chief development of the marble industry is taking place.

The position of the marble-bearing rocks is indicated topographically by a well defined valley for the greater part of the course, but in a few places the valley is diagonally crossed by elevations which mark the position of more resistant rocks. These elevations form the few watersheds in the valley.

The phyllite area to the southeast rises to a considerable elevation above the valley. The dolomite lands to the northwest of the marble are also slightly elevated above the valley and frequently form broad, fertile, low tablelands on that side. The phyllite areas which occur on the northwest side of the marble are marked by sharp ridges. In one case the

phyllite ridge runs parallel with the marble for nearly four miles, but in the other cases the phyllite ridges diverge from the marble and allow dolomite lands to intervene.

The occurrence of the Alabama marble wholly at low elevations in a well defined valley presents a striking contrast to the occurrence of the

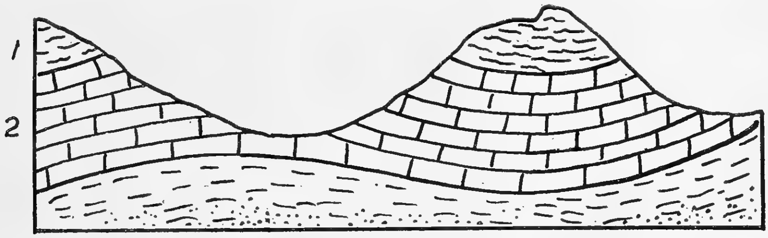

FIGURE 1.—*Idealized Section, showing the Marble-Schist Contact high above the drainage Lines as represented in some Areas of the Vermont Marble Deposits*

1. Schist. 2. Marble

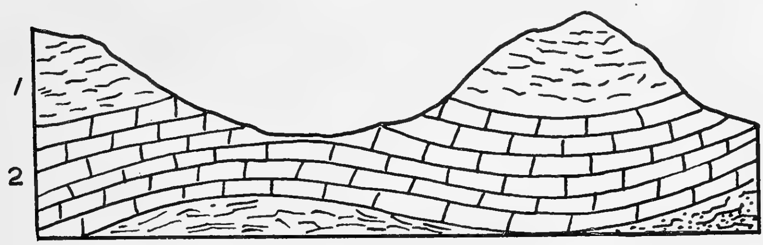

FIGURE 2.—*Idealized Section, showing the less elevated Position of the Marble-Schist Contact above the drainage in the Georgia Marble Deposits*

1. Schist. 2. Marble

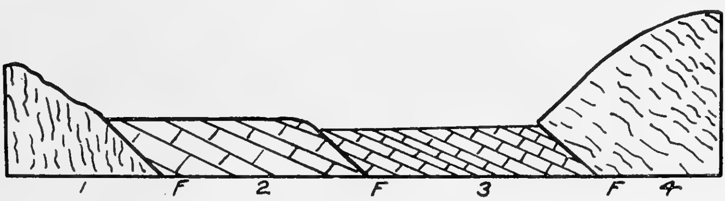

FIGURE 3.—*Idealized Section, showing the topographic Relations of Schist, Marble, and Dolomite in the Alabama Marble Deposits*

1. Phyllite. 2. Dolomite. 3. Marble. 4. Talladega phyllite. F. Fault

Vermont marble deposits and also to the occurrence of many of the Georgia and Tennessee marble deposits. In the Vermont area many of the quarries are high above the drainage lines and there are large areas of outcropping marble on the slopes. In Georgia and Tennessee the same is true, with the exception that the line between the marble and the overlying schist is at a relatively lower elevation on the valley slope. This

difference of the topographic situation of the marbles of Vermont as compared with Georgia and Tennessee is apparently in part due to the greater chemical activity in weathering in warmer climates, but in the case of the Alabama deposits this explanation is not alone sufficient. A comparative study of the cross-sections through the different deposits does, however, supply the needed information.

The Alabama marbles, figure 3, are separated from the overlying schist by a fault which provides a zone of more rapid solution than is the case in Georgia, where the climatic conditions are similar.

Throughout the marble field there are very few natural exposures of marble, and these occur only along the streams or where the rocks have been sharply folded or faulted. The fact that the marble in some of the earlier developed quarries proved very unsound is due to their location on these natural outcrops above the drainage levels, where fracture, due to the unusual disturbance, is greater than elsewhere and where weathering, due to the exposed position of the rock, has been abnormally great.

STRUCTURAL CONDITIONS

Faulting.—The structural conditions in the marble area are such as would result from a shortening of the earth's crust, due to lateral pressure, with accompanying reverse faulting, minor folding, and shearing stresses. The reverse fault on the southeast side of the marble area varies considerably in throw. In many places the main fault is paralleled by a second fault a few hundred feet distant to the northwest in the marble valley.

The general northeast and southwest trend of the marble valley is sharply altered in several places by offsets (see map of the marble deposits). The largest offset has a lateral displacement of the valley of over three miles and is caused by a combined fault and fold. In many places small offsets occur along nearly parallel oblique or dip faults. This is well illustrated in the accompanying figure (figure 4), which shows the condition near the Herd quarry, a little north of Sylacauga.

Dip.—The dip of the marble is remarkably uniform throughout the field. It varies, as a rule, but little from 30 degrees and is in a general easterly direction.

Schistosity.—In most of the marble exposures there is evidence of shearing stresses. Slipping has taken place for the most part along the schist planes, but in some cases the slips are evident in the marble itself, forming the so-called "reeds" of the quarrymen. This slipping in the marble is sufficient in one locality to render the marble distinctly schistose. Figure 5 shows a hand specimen of such marble taken from the

northern part of the field, and figure 6 shows photomicrograph of a slide taken from this specimen. The schistose character of this marble has been noted by Van Hise[4] and by Leith,[5] although the localities cited by them are incorrectly given as from Talladega Mountain, Alabama, and from Talladega Mountain, Georgia.

The direction of shearing in the marble, as recorded in the slip grooves, is in most localities nearly parallel to the dip. A study by the microscope

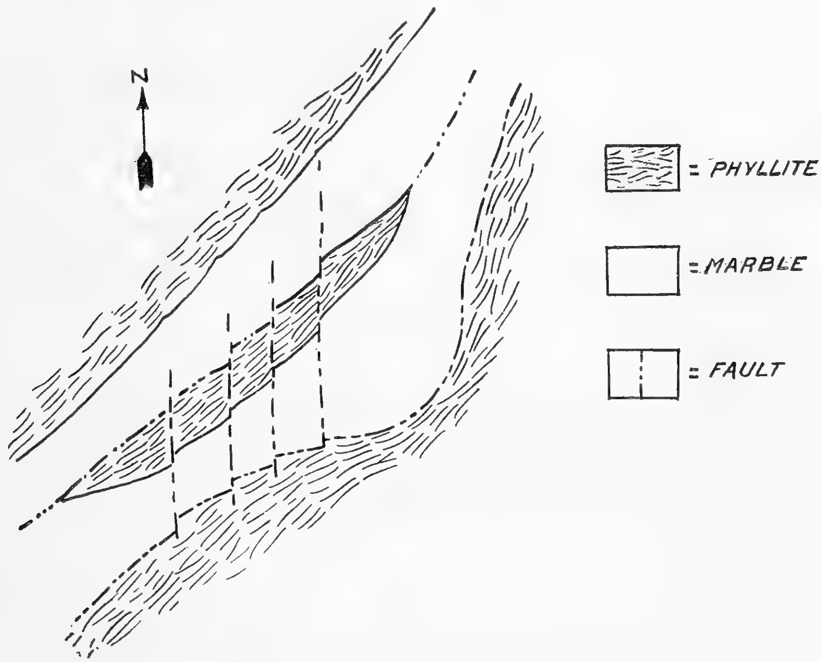

FIGURE 4.—*Diagrammatic Representation of minor Offsets in the Marble Deposit*
The offsets are caused by diagonal faulting and a repetition of the marble outcrop caused by strike faulting. The locality is near Herd quarry

of thin sections of the marble cut in different directions in a plane perpendicular to the bedding also shows that the greatest elongation of the calcite crystals is parallel to the slip direction. In many cases also a microscopic study of thin-sections taken from well within the sound marble block shows the calcite crystals to have a distinct elongation.

Joints.—Both tension and compression joints are well represented in the marble (see figure 7). The compression joints, which are the ones oblique to the strike, are usually the more important ones. In some locali-

[4] Charles R. Van Hise: U. S. Geological Survey, Monograph 47, pp. 810-811.
[5] C. K. Leith: Bull. 239, U. S. Geological Survey, p. 41, pl. 16.

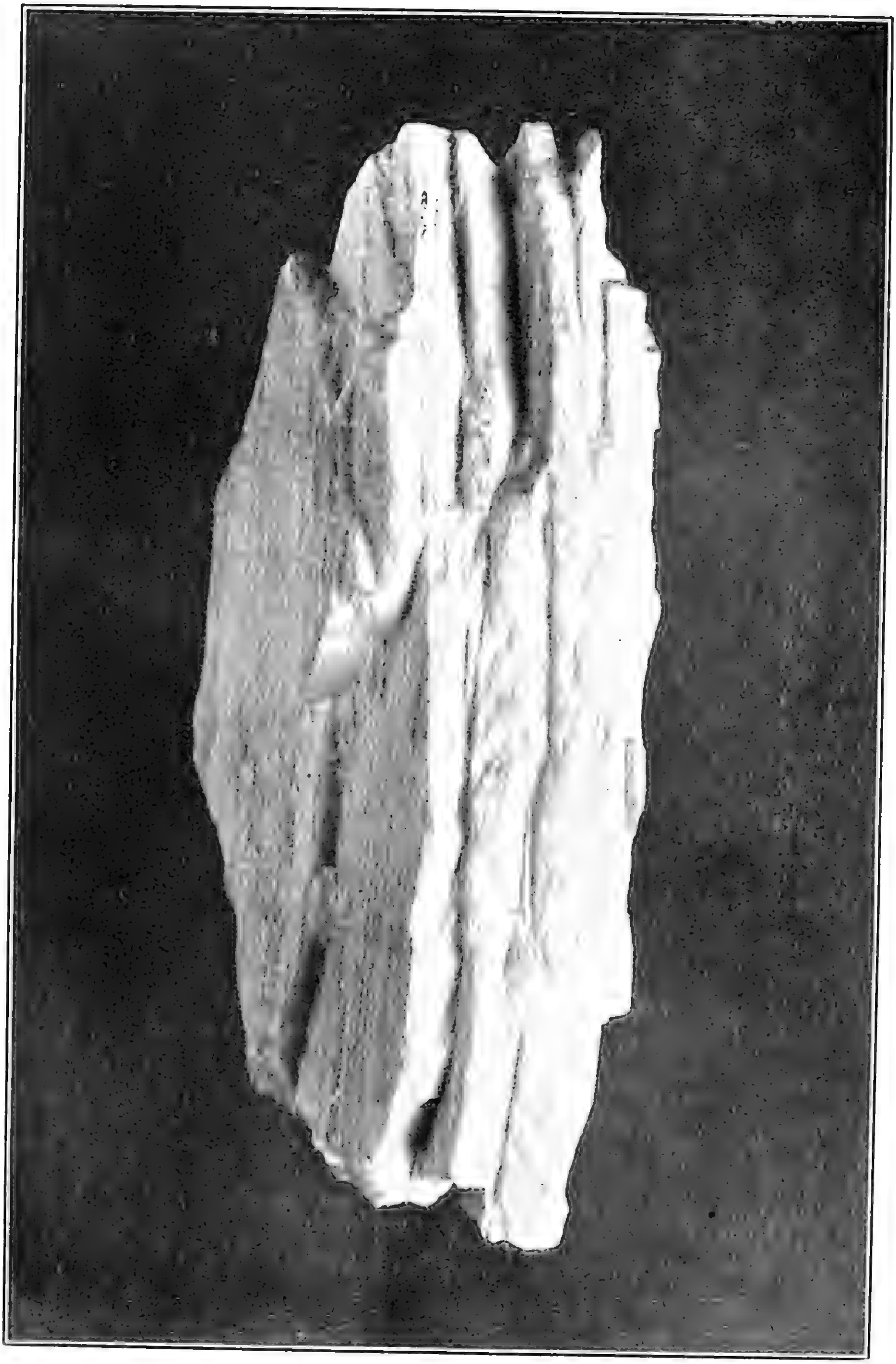

FIGURE 5.—*Schistose Marble from near Taylors Mill*

The crystals of this marble are distinctly elongated in the direction of the striation seen in the photograph. (See figure 6 for photomicrograph of thin-section of this marble)

ties these diagonal joints have a distinctly radiating character, such as would result from torsional stresses. Such torsional stresses would occur in case of unequal support of the strata or uneven distribution of resistance to the compressive forces. Figure 7 shows the nature of the jointing in one of the quarries of the marble area. The lines represented in the figure are the intersection of the jointing planes with the plane of the bed prospected.

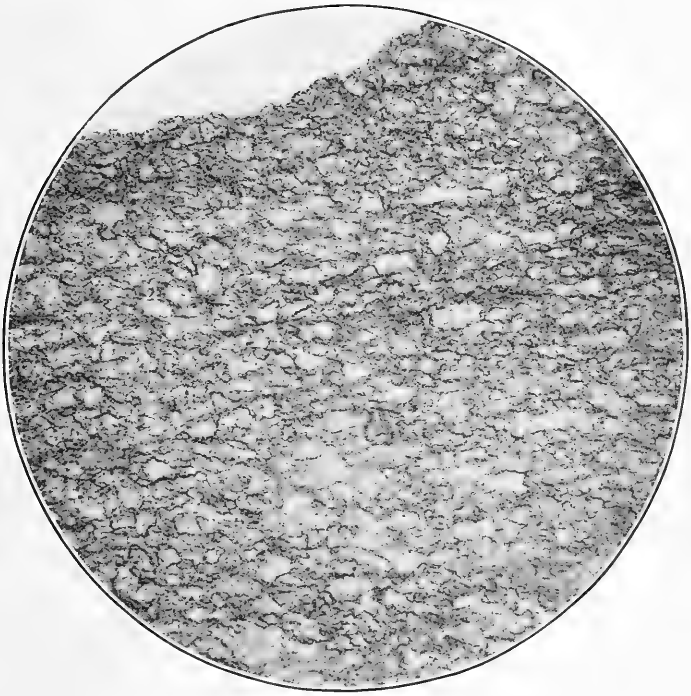

FIGURE 6.—*Photomicrograph of schistose Marble from near Taylors Mill*

The crystals are distinctly elongated. The average maximum grain is about .16 mm., which shows the marble here to be much less metamorphosed than at other places in the field. At the time of metamorphism it must have been less deeply buried, and therefore less easily deformed without shearing than the marbles elsewhere in the field. Magnified 50 diameters. Compare with figure 8, which represents marble from Gantts Quarry with same magnification.

Drag-folding.—Evidence of drag-folding in the marble is frequently seen. In one of the quarries many of the blocks, which are taken out parallel to the general dip direction, show an angle of as much as 15 degrees between the minor schist lines in the block and the general bedding planes (see figure 9).

In all exposures the marble is much more unsound at the surface, due

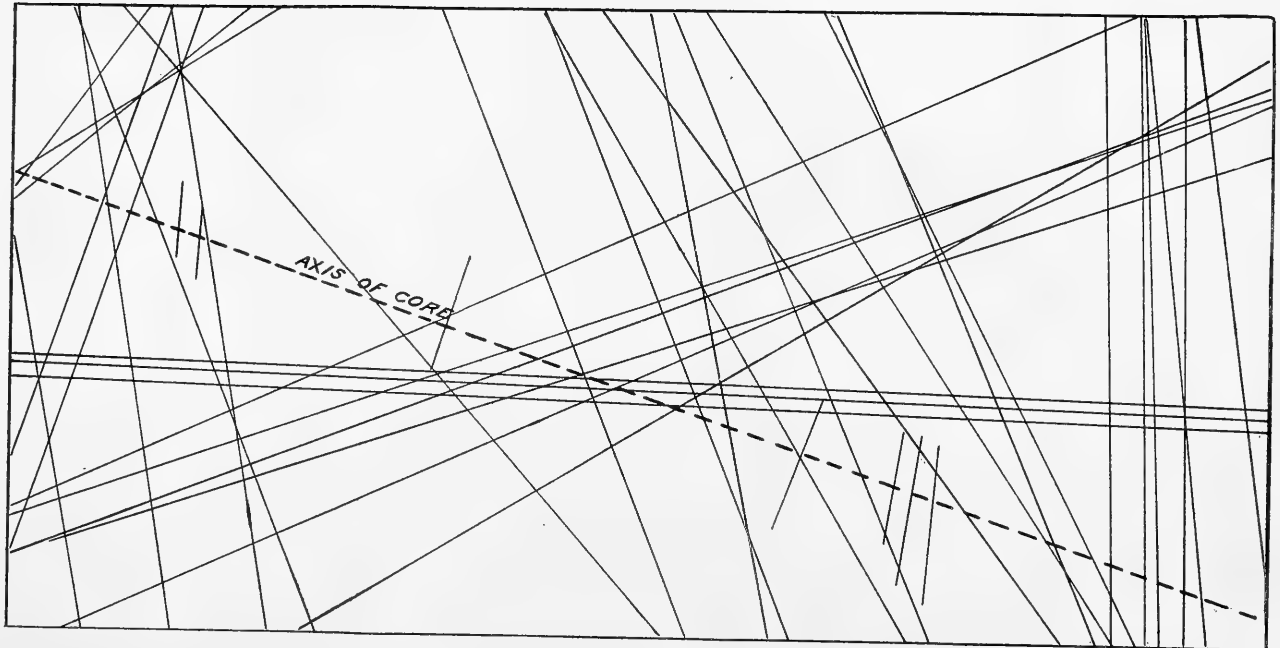

FIGURE 7.—*Diagrammatic presentation of Jointing in a Portion of one of the Quarries in the Alabama Marble*

The short direction of the rectangle is the strike direction and the long direction is parallel with the dip. The lines represent the intersections of the jointing planes with the bedding plane. The dashed line represents the direction of the diamond drill core in the bed prospected. Three expansion joints or "slicks" are to be seen close together near the center of the rectangle parallel to the long direction. The few strike joints are apparently tensional joints, while the diagonal joints are the result of compression. The radiating character of some of the joints is probably due to torsional stresses. There are certain zones in the rock which are very much jointed and other zones which are relatively free from unsoundness. The jointing system here represented is the result of data gathered by core-drilling the layer in question. This method is being used with success by Major J. S. Sewell, of Gantts Quarry, Alabama, and the above represents one of his prospect maps.

to weathering, than it is deeper in the deposit. The chief agents of unsoundness in the marble in the upper few feet of the quarry are the

FIGURE 8.—*Photomicrograph of the commercial Grade of Alabama crystalline Marble magnified fifty Diameters*

Note the interlocking character of the crystals and the twinning bands. The thin section from which this photograph was taken came from about one-half inch below the surface of a slab of marble which has been exposed to continuous weathering for over 60 years and which shows practically no iron stain and which has retained the very finest lettering in an almost perfect condition. The average maximum grain size is .57 mm. This makes the marble a little finer grained than the average Vermont marble.

so-called "slicks" (vertical planes of parting), which run directly down the dip and decrease with depth. These planes of weakness are similar to the vertical joints which occur in concrete dams at right angles to their length, which result from expansion and contraction due to changes of temperature. This tendency for the marble to be less unsound deeper in the quarry is also found to be the case in the individual beds. Figure 10 represents the decrease in throw and the final disappearance of the small faults seen in one of the blocks taken from the quarry.

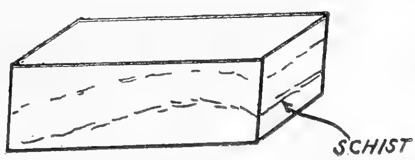

FIGURE 9.—*Diagram of Schist Lines in Block of Marble at variance with general bedding Direction, due, it is thought, to differential Movements in the layer because of Drag.*

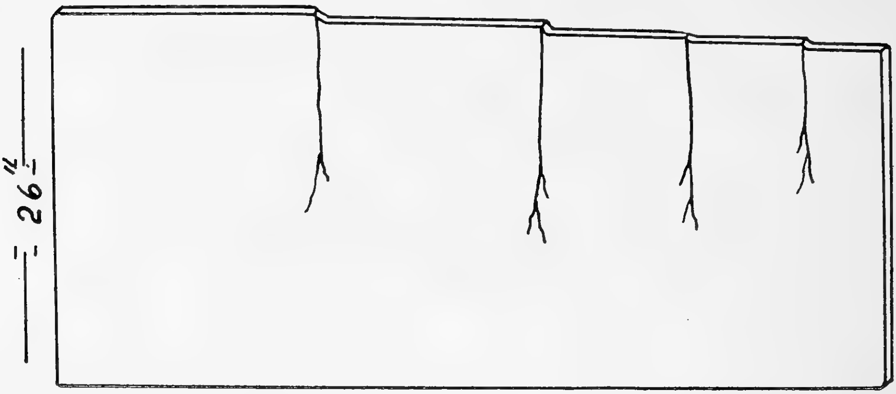

FIGURE 10.—*Diagrammatic representation of a Slab of Marble taken from Block at right Angles to the bedding Plane*

The faults show a displacement on the surface of the block of from one-half to three-fourths of an inch. Within 16 inches of the surface all sign of faulting has disappeared.

CROSS-SECTIONS OF FIELD

There has not been sufficient prospecting within the marble field to establish the maximum thickness of the marble deposits. In the neighborhood of Gantts Quarry, where most prospecting with the drill has been done, the following section (figure 11) has been recorded:

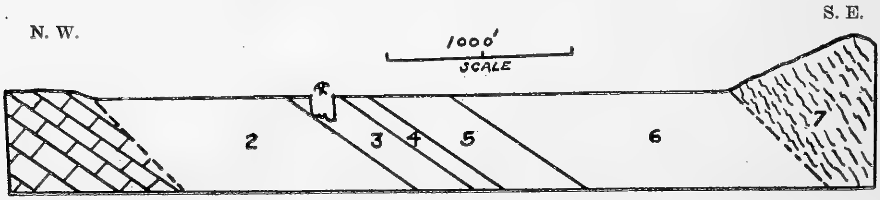

FIGURE 11.—*Cross-section through Marble Valley at right Angles to Strike*

1. Dolomite. 2. Probably dolomite and marble. 3. White marble, 175 feet thick. Gantts Quarry in this layer. 4. Blue low-grade marble; too poor to work; 75 feet. 5. Mostly white marble, 225 feet. 6. Not prospected, but probably dolomite and marble. 7. Talladega phyllite.

About three-quarters of a mile to the northeast of Gantts Quarry the following section (figure 12) holds:

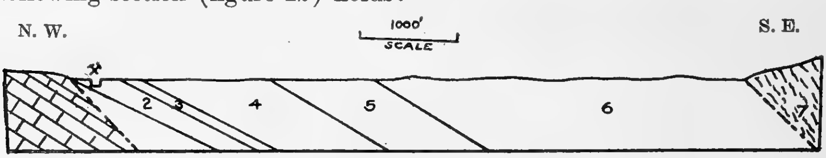

FIGURE 12.—*Section through Marble Valley at right Angles to Strike*

1. Dolomite. 2. White marble, Moretti-Harrah Marble Company's Quarry here. 3. Marble, with considerable schist and pyrite; not workable. 4. The lower 70 feet good marble; the rest is probably largely marble. 5. Dolomite, with some marble. 6. Unprospected; probably some marble. 7. Talladega phyllite.

A few miles northeast of Sylacauga, where the field narrows and is bordered on either side by parallel ridges, the following section (figure 13) is approximately correct:

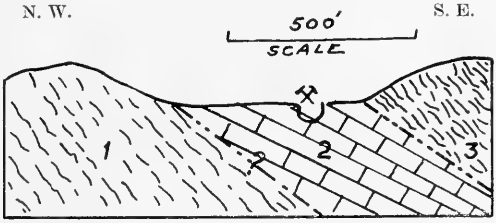

FIGURE 13.—*Section through Marble Valley at right Angles to the Strike*
1. Phyllite similar to that on east side. 2. White marble, with opening of Alabama Marble Quarries Company here. 3. Talladega phyllite

RELATION OF CALCITE AND DOLOMITE

In many parts of the field the calcite marble is interbedded with dolomite. The line between these two minerals is a very sharp one, as is shown by the study of thin rock sections taken through the contact. Frequently there is a thin film of iron oxide separating the two minerals. This interbedding of dolomite and calcite has been observed in the Knox Dolomite formation, which lies to the west of the main marble belt for a considerable portion of the field. Frequently these beds are very thin. The following section (figure 14) is taken from an outcrop in a sink about three miles southwest of Gantts Quarry and illustrates on a small scale what takes place in thicker beds elsewhere in the field.

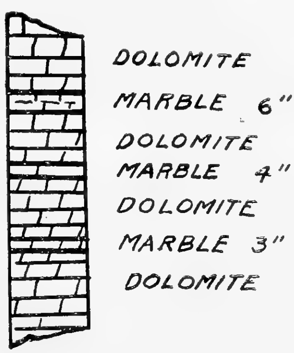

FIGURE 14.—*Section from the Knox Dolomite Area just to the west of the main Marble Belt.* Showing the interbedded character of the sharply defined beds of calcite marble and dolomite.

It is evident from the sharp line between the calcite and the dolomite that there must have been a difference in the character of the originally deposited materials in these beds. Whether this difference was physical or chemical cannot be told from the present investigation; but if there was not an original deposition of dolomite the mineral originally occupying the place of the dolomite was exclusively favored in the replacement process.

CHARACTERISTICS OF THE MARBLE

The Alabama marble is usually described as a fine-grained white marble. It exhibits more or less chloritic and talcose veining and clouding.

The chief attractiveness of Alabama marble is due to its life and to its warmth of coloring. The white marble is for the most part a cream white rather than a bluish white, the more common characteristic of the Italian marble. The Alabama marble is, moreover, unusually translucent, in this characteristic resembling the famous Parian marble. A number of varieties of Alabama marble result from the different directions in which the blocks are sawed. Banded marble, clouded marble, or marble of nearly uniform color result from cuts respectively at large angles, at small angles, and parallel to the schist line in the stone.

Alabama marble is slightly finer in grain than the Vermont and very much finer than the Georgia marble. The crystals are also very much interlocked, as a rule (see figure 8), giving toughness to the stone, but making it more difficult to saw than the Vermont marbles. The low absorption and high compressive strength and sonorousness which the Alabama marble possesses to a marked degree is to be expected from the fine interlocking character of its grains.

Chemically the Alabama marble is a very pure calcium carbon. The chief impurities are silica and magnesia. Iron is usually very low. In most cases when there is a small amount of magnesia or a trace of it, its presence is to be accounted for by its occurrence in the chlorite or talc which furnish the chief coloring agents in the marble.

QUARRY METHODS

On account of the more distinct bedding in the Alabama marble deposits than in either the Vermont or the Georgia, the method of quarrying in Alabama is considerably different from the method employed in either of these States and more like that in Tennessee. The blocks in all cases are taken out parallel to the bedding plane and also parallel to the main lines of unsoundness (see figure 15), whether this unsoundness is down the dip or oblique to it. It was the early practice in some of the quarries to run the channeling machines parallel with the dip, irrespective of the direction of the main joints or "headers," but such practice has proven very wasteful. In the background of the photograph (figure 15) is seen the old method of quarrying directly down the dip, and in the foreground of the picture can be seen the new method of making cuts for the blocks parallel with the main lines of unsoundness, in this case not in the direction of dip.

In the quarry of the Alabama Marble Company (the largest marble company in the State) tunneling is now being employed in order to secure the largest possible floor space with the least possible expense, and at the same time to develop this floor space in the marble deep in the quarry, where unsoundness from weathering is at a minimum.

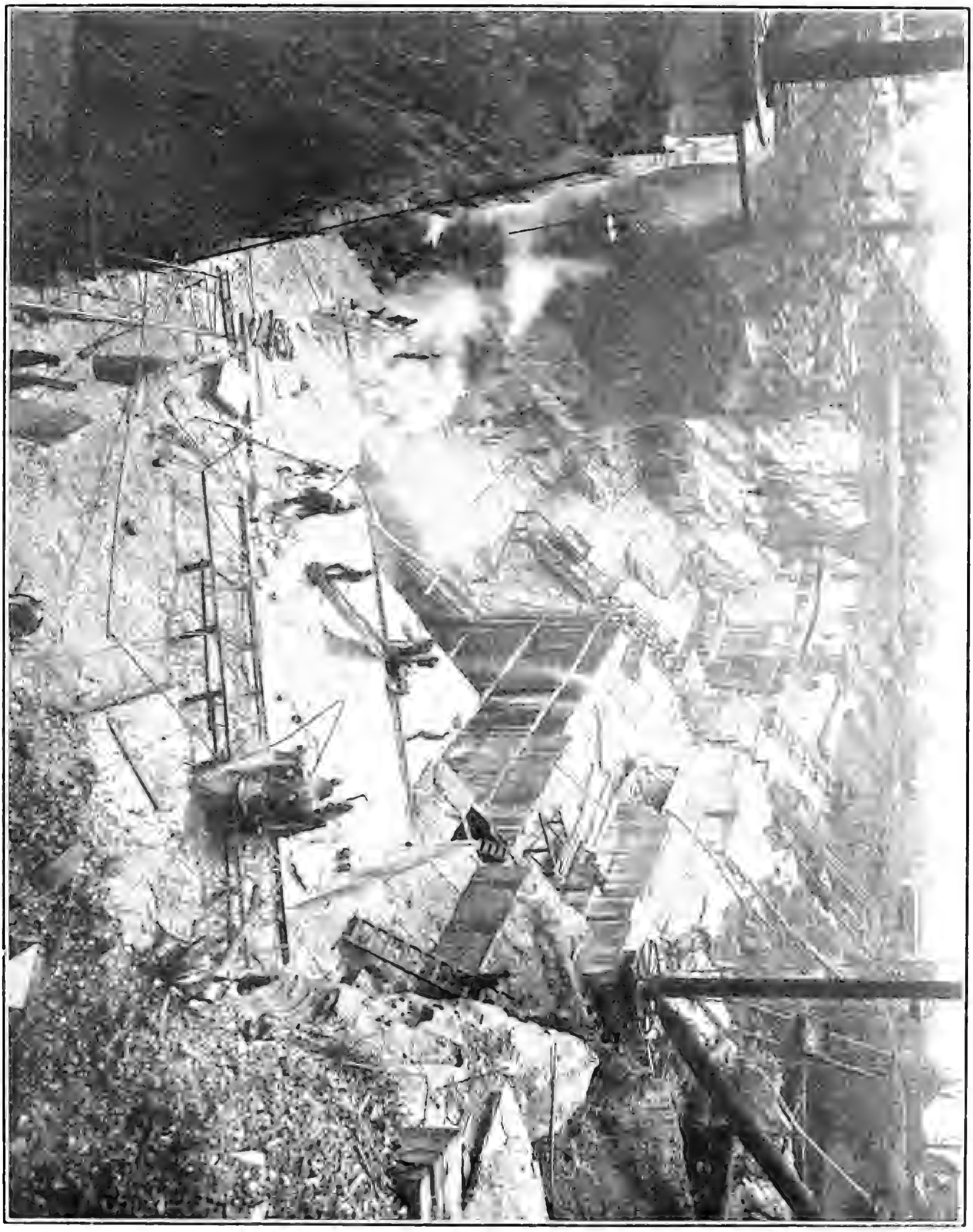

FIGURE 15.—*View looking nearly west into Gantts Quarry*

It is not possible to secure as high a percentage of sound marble from the Alabama marble quarries as from the quarries of Vermont and Georgia, but the percentage of marketable stone can be very largely augmented by skillful quarrying, sawing, and finishing. As the Alabama marble has many characteristics unlike other marbles, it is commercially advantageous to have the marble quarried, sawed, and finished under the same management.

On account of the lower percentage of marketable stone to be gotten from the quarry blocks and the slightly higher cost of sawing and finishing, the Alabama marble must be sold at a slightly higher price than other competing marbles, such as from Vermont, Georgia, and Tennessee; but despite this handicap in price, the Alabama marble has a well established and rapidly growing market, as shown by its extensive use and popularity in many of the great cities in all parts of this country and in Canada.

The demand for Alabama marble warrants the establishment of a number of large plants for quarrying, sawing, and finishing. These companies should have large capital in order to carry the development to a point where the profits will be substantial.

MAPPING THE MARBLE

In mapping the marble area the author has found that a careful study of the topography is of the greatest aid, since the marble usually occupies the lowest ground of any of the associated rocks. The study of the soil is also very helpful. It has been found that the residual soil from the marble beds is less intensely colored by iron oxide than is the soil from the dolomite bordering it and frequently interbedded with it. A microscopic study of thin sections of marble and of dolomite show that the dolomite has larger amounts of associated iron oxide. It must be borne in mind that in many places the mantle rock above the marble is transported and not residual; furthermore the surface wash on nearly level lands, which have stood for some time without being plowed, will concentrate the sand at the surface and give to the land an abnormally gray appearance, thus causing one to think the rock below is marble rather than dolomite. Sinks are somewhat more common in the marble than in the dolomite. In some places the marble area is bounded on the west by a distinct line of massive chert boulders marking the position of the boundary fault. Lines of springs are more common on the borders of the area than in it, as would be expected from its fault-block character.

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JOSEPH STANLEY-BROWN, EDITOR

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CONTENTS

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 27, PP. 451-490 JUNE 23, 1916
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

CORRELATION BY DISPLACEMENTS OF THE STRAND-LINE AND THE FUNCTION AND PROPER USE OF FOSSILS IN CORRELATION [1]

BY E. O. ULRICH

(Read before the Paleontological Society August 3, 1915)

CONTENTS

[1] Published by permission of the Director of the U. S. Geological Survey. The terms Ozarkian, Canadian, St. Croixan, and some details of classifications as used in this paper have not yet been adopted by the Survey.

Manuscript received by the Geological Secretary April 6, 1916.

This paper was read at the Summer Meeting of the Paleontological Society, at the University of California, August 3, 1915, and was the first of a symposium entitled "General consideration of paleontologic criteria used in determining time relations."

INTRODUCTION

EFFECT OF VARYING CIRCUMSTANCES ON PRINCIPLES AND CRITERIA OF CORRELATION

The practice of stratigraphic correlation—that is, the determination of the time relations of marine and continental deposits in widely separated areas by other means than continuous tracing of beds—is rarely a simple process. Often, indeed, the problems to be solved prove exceedingly intricate. With the progress of the science many rules and criteria for establishing contemporaneity in geologic events have been suggested and applied with varying success in the practical work of the geologist. At first most of these rules and criteria seemed sound in principle and widely, if not universally, applicable; but as our stock of facts increased, the correlations indicated by them became more and more uncertain.

At present there are no formally recognized rules that, taken either singly or in combinations, will insure uniformly reliable results under all circumstances. Criteria whose worth has been proved for one geological province fail more or less decidedly in another, and their failure is not in proportion to the distance between such provinces, for it may be greater where the separation is measured by only a few miles than in other instances in which provinces of different continents are involved; in fact, the mere matter of distance plays but a subordinate part in the contemporary variability of faunas and floras. Fossil marine faunas, for instance, may extend in essential purity for great distances in one direction, whereas in the opposite direction they may cease abruptly and perhaps appear to give way to a totally different fauna.

Such abrupt changes in the fossil contents of beds similar in lithologic character and apparently occupying corresponding positions in the geologic column may seem difficult to explain; and instances of this kind are not at all uncommon in the Appalachian region. However, without exception the faunally distinct, though apparently contemporaneous, beds have proved to be not only of different ages, but, what is of much greater

consequence in the composition of the fauna, they represent invasions from different oceanic basins.

Though experience shows it to be an unlikely condition, it is yet conceivable and physically possible that such diversely originating invasions might have occurred at the same time and their heads approached each other closely. So long as they remained separate, their respective faunas would have maintained their characteristics; but so soon as confluence was established, either one or the other fauna must have dominated the life in the joined embayments, or a mingling of the two must have ensued. Either result is to be included among the means by which the faunas of different oceanic basins acquired or interchanged specific and varietal units that are of the highest importance in correlating their respective deposits.

The reason why many correlation criteria fail when they are employed in other provinces than the one in which their value has been unimpeachably established is that the circumstances on whose unvarying maintenance they depend change from place to place. Indeed, all nature attests the impossibility of conditions continuing unchanged everywhere. Each case, therefore, demands a prior determination of the probable changes in circumstances which have made it different in some corresponding degree from the proved cases that are accepted as the standard by which the others are to be measured.

These changes commonly are grounded in physical phenomena, which bring about corresponding modifications in the locally prevailing organic facies. The lands that contribute material to build up the floors of the continental and oceanic basins may be higher or lower than the average; one area may be elevated, another depressed; the climate may be moist or uncommonly dry; the run-off of the streams may be rapid and their waters loaded with sediment, or it may be slow and the waters clear. All these variations would have some effect on the existence and character of the land animals and plants, and on the character of the deposits that were laid down in the water-filled basins or on favored parts of the land; and they would also tend to change the character of the faunas that live in the seas. Conditions favoring the existence of certain kinds of life would be introduced in one set of places, while other places would have become inhospitable to the same organisms, though perhaps exceptionally attractive to other kinds.

Differential movements of the surface of the lithosphere also may result in great and sometimes complete changes in the local composition of marine faunas. For instance, a continental basin that had previously been connected with the Gulf of Mexico might be so tilted that the south-

ern waters and faunas would be excluded and replaced by north Atlantic waters and faunas. Such reversals happened many times during the geologic history of the North American Continent. There were times, too, when the northern continents were connected by strips of low land or shallow water that favored intermigration of sublittoral faunas. These and other warpings of the sea-bottom resulted also in changes in the course of marine currents and in corresponding changes in the distribution of floating organisms.

All of these changing conditions, save the last, tend to invalidate the principle of correlation by comparison of the general aspect of faunas. Unless short-lived species are positively identified in both, mere similarity in aspect, however great, can not of itself establish the contemporaneity of two fossil faunas.

INFLUENCE OF BOTTOM AND DEPTH ON MARINE FAUNAS

Marine faunas are greatly influenced by the character of the bottom on which they live. Some species prefer and may be confined to sandy bottoms, others live only on muddy bottoms; but such variations in environment are of smaller consequence to the paleontologist than is commonly supposed. He works chiefly with the fossilized, hard parts of animals, and these, obviously, are carried by waves and currents far and widely beyond the areas in which they lived. The more or less fragmentary remains of faunas, whose natural habitat is in one case a sandy bottom, in another a calcareous mud bottom, or in a third a clayey mud, may thus be mechanically associated in the same layer. This happens commonly in shale formations which contain small lenses of sandstone or limestone, or both. A true indication of the limits imposed by bottom conditions on the existence and distribution of particular faunas is preserved chiefly in formations that consist of or include widely extended and uniformly developed lithologic units. The fossils preserved in such beds doubtless represent many originally distinct colonies, but all of them lived on essentially the same kind of bottom. Occasionally, too, original colonies, which must have been rapidly or suddenly buried, are found. Original associations also are found in the crevices of algal and coral reefs and between the boulders of a rocky shore.

Correlations requiring the assumption of lateral change in faunas caused by differences in character of bottom are, so far as my experience is concerned, commonly found to be in error. As a rule, the observed differences in the faunas resulted from altogether different causes. The use of the idea in correlation seems to be warranted only as a last resort.

Bathymetric differences also cause great changes in marine faunas;

but the knowledge that the shallow-water faunas of the present seas are very different from those living on the bottom at depths of 1,000 feet or more is of little practical value to the stratigraphical paleontologist. It is of little value to him, because the fossiliferous beds which he is called on to study or correlate have been, so far as I know, without a single well established exception, laid down in waters that varied too little in depth to have suffered much change in faunas on that account.

PRECEDING PAPERS ON THE SUBJECT OF CORRELATION

On at least two occasions my views on the criteria and principles of stratigraphic correlation have been expressed in considerable fullness. The first of these appeared in my Revision of the Paleozoic Systems, published by the Geological Society of America in 1911; the second in a paper delivered before the International Geological Congress at Toronto in 1913, and since published in the proceedings of the session. The former, a work of 400 pages, is devoted almost entirely to the discussion of the criteria and principles, those pertaining to the lithologic and other physical aspects of the problem being treated quite as fully as the paleontologic. The second paper, covering 75 pages, begins with a concise statement of the principles of correlation, with special reference to stratigraphic taxonomy. The object chiefly in mind on this occasion was to illustrate the practical and scientific value of the diastrophic methods of classification, as defined and recommended in the larger work, by its application in a well known and supposedly difficult case, namely, the Ordovician-Silurian boundary in America.

The essentials of the present effort are contained in these published papers. But, strictly speaking, there is little of repetition in these papers, and what there is pertains wholly to the statement and general discussion of principles and criteria. The illustrations are new and some have developed only during the past year or two; in fact, there is no lack of examples that may be cited as proving the inadequacy and imperfection of correlation methods commonly practiced. Their abundance, moreover, forces the regrettable conclusion that the errors which have resulted from the prevailing practice are more the rule than the rare exceptions which they should be.

NEW CRITERION IN CORRELATION

Although the greater part of the following discussion may be described as destructive criticism, I trust the reader will find also much that deserves to be characterized as constructive. Comprised in the latter is a new organic criterion that is of exceeding and obvious value. Its value

lies in this—that it identifies geological horizons as positively and as closely as it is possible to do so by means of fossil evidence. The new criterion is based on the logical belief that combinations of biologically unimportant characters can have existed but once, and that they endured for only short periods of time. Accordingly, absolute identification of such minor modifications of species in widely separated localities is regarded as establishing the essential contemporaneity of these occurrences.

The application of this criterion involves the utmost refinement in the discrimination of fossils, for the greater the detail and the smaller the distinctions, the more exact the correlation. The basic idea is too obvious to be called new, but, so far as known to me, it has not hitherto been formally recognized as a principle in correlation. In my own practice, however, and despite the fact that it subjected me to reproach as a "species maker," the identification of minute organic differences has for many years played the most important part in my work as a paleontologist and stratigrapher. The method of minute discrimination of fossils was early favored because it always led to dependable results. Later it seemed the best, if not the only, safeguard against the confusion of recurring faunas or species. Judging from the results of my work in stratigraphy during the past 20 or 25 years, this method has proved vastly superior in definiteness and accuracy to all other methods of correlation by fossils. Stratigraphic correlation by relative similarity in general faunal aspect commonly is indecisive, and often, indeed, such comparisons are positively misleading. In my opinion, then, "preponderance" of generic or broadly specific affinities, however great, should never outweigh the dissenting evidence of two or three exactly identified varieties. Subordinating the latter would be like accepting hearsay evidence in preference to the testimony of a photographic picture.

Another new conception seeks to explain the not uncommon apparent discordance of the evidence of marine animals on the one hand, and that of land organisms on the other. It is explained by the reasonable assumption that whereas land animals and plants flourished best when the lands attained their greatest development, hence during and shortly preceding and succeeding the intersystemic intervals, the shallow-water marine animals, on the contrary, experienced their least stressful periods when the seas encroached on the lands and thereby increased the total area of shallow seas. The greatest changes in the land organisms, therefore, occurred in the middle ages of the geological periods, when their range was most restricted and submergent conditions dominant, whereas the marine animals changed most in the transition stages from one period to the next, when emergent conditions prevailed and the lands, therefore,

were larger and the continental shelves correspondingly narrower than in the middle stages of the periods.

TRUE FUNCTION OF FOSSILS IN STRATIGRAPHIC TAXONOMY

Regarding the function of fossils in correlation, I hold that it consists chiefly of the means they afford of identifying geological horizons. This conclusion is indicated by the fact that life is a continuous process, and that the fossils represent merely occasional stages in its evolution. The first appearance of a species in a stratigraphic sequence does not mark its inception, nor is it likely that its latest appearance in the column marks its extinction. As a rule, the species continued to exist somewhere, and under the stresses incident to sea retreat it gave rise to modified descendants which, when opportunity again offered, invaded the reestablished continental seas and left remains that became the guide fossils of the succeeding age.

Furthermore, the life on the several continents and in each of the oceanic basins differed greatly in character and evolution, and its development in each was not uniform in direction and rate of modification. Many types were confined to a single area or basin, some lingered much longer in one realm than in another, and others, before becoming extinct in their original habitats, migrated to distant areas, in which they then continued to live for a long time after their extinction elsewhere.

Even when all these complicating factors have been accounted for and the age of a fossiliferous bed has been properly determined, the purely paleontological method of classifying deposits into formations, groups, series, and systems commonly fails in a most important particular, namely: it does not exactly locate the contact between directly superposed sediments of different ages. As the contact commonly marks some time break whose exact location in the section is essential to a proper understanding of the geological history of the region, the need of some other criterion that will assure greater definiteness in the delimitation of stratigraphic units is obvious. To meet this demand, we are obliged to revert to those physical criteria of diastrophism which indicate displacement, by advance or retreat, of the strand-line.

Methods of Correlation

UNIFORMITY AND CONSISTENCY IN PRACTICE ESSENTIAL

The most prolific source of disagreement among systematic stratigraphers lies in the prevailing disregard of uniformity in taxonomic methods. One geologist bases his judgment regarding the position of a given bed

in the standard time scale on the general aspect of the fauna of the bed in question; another considers the introduction of new faunal types, or the mere presence of one or more supposedly characteristic species, as surer, or at least more definite, indications of a particular time; a third considers both of these methods, but inquires also into the origin and migration of the faunas and floras, and is finally guided, especially in drawing boundaries, chiefly by physical criteria indicating breaks in the process of sedimentation. The method of the first is that of simple matching of faunas and floras. The second also draws his conclusions by "matching," but in his case the process is complicated by discrimination and weighing of factors. Both, however, depend either wholly or mainly on strictly organic criteria. The third follows the diastrophic method, which, as we shall see, is the most comprehensive and scientific of the three, and consequently leads to more definite results. All three of these methods are being followed by paleontologists today, but happily the first is no longer regarded as sufficient by those who have acquired a practical field knowledge of stratigraphy.

There is also little uniformity in the practice of geologists regarding the age assignment of clastic deposits connected with a break in geologic history. The break may be widely or generally determinable, and thus of high significance in stratigraphic taxonomy, or it may be but locally expressed and correspondingly insignificant. In either case the physical evidence indicating the break may or may not be clearly discernible by the average geologist, but its presence is always suggested by some change in the faunas, and its plane is usually exactly determinable by those trained in such investigations. Deposits of this kind have been interpreted by some as the closing facies, while others have described them as introducing the succeeding age. The latter view doubtless is the more correct, even when the new deposit agrees closely in lithologic character with the underlying formation.

Initial deposits closely simulating the older formation occur as a rule when the latter is a sandstone whose top in the meantime has been subjected to subaerial conditions. Commonly it is easy enough to distinguish the reworked sand of the new deposit from the old, but when the simulating material constitutes not only the basal deposit of the superposed formation, but is succeeded by similar sandstone to its top, so that we have two sandstone formations in contact with a known or unknown break between them, the task is not so easy. But it is never hopeless, and no more difficult if the hiatus is small than when it spans two or three geological periods.

UNCONFORMITIES IN THE CAMBRIAN SANDSTONES AT ABLEMANS, WISCONSIN

Two problems of this kind were solved this summer in Wisconsin. Both related to early Paleozoic sandstones that had been confused. The first instance was found at Ablemans, a noted locality to the west of Baraboo, where an unusually hard and supposedly unfossiliferous Cambrian sandstone lies in sharply eroded old valleys in the Precambrian Baraboo quartzite. A year ago I visited the large quarries at Ablemans and decided that the sandstone filling the old valleys is of the age of the Dresbach sandstone of Minnesota. Over this sandstone were remnants of another sandstone formation that a short distance to the north is seen to spread unconformably over the lower sandstone and the surrounding hills of quartzite. Its base is formed by a heavy bed of conglomerate, composed almost entirely of perfectly rounded pebbles 2 to 6 inches or more in diameter. Except that this upper transgressing sandstone forms the base of the Ozarkian system in this region, it has no immediate interest in this connection. I should add, however, that the identifications made in the vicinity of Ablemans necessitated the assumption that the Cambrian formations normally intervening in Wisconsin between the two sandstones recognized here—namely, the Franconia sandstone, the Saint Lawrence formation, and the Jordan sandstone—were absent here either through nondeposition or pre-Ozarkian erosion.

During the past winter I received notice that a number of specimens of a brachiopod which were recognized as belonging to a species that till then, and I am glad to add even today, is thought to be confined to the lower fourth of the Franconia formation, had been found in the sandstone which I had identified as Dresbach. As might be supposed, this information proved somewhat disquieting. If my judgment was wrong, the way to benefit by the experience was to see the facts for myself in the field. Accordingly, in June the State Geologists, Mr. Hotchkiss, and his assistant, Doctor Weidman, accompanied me to Ablemans.

Well, it required little more than one hour to satisfactorily explain the difficulties. The quarry in which the Franconia fossils had been found was the first to be visited. Its face exceeds 100 feet in height. The greater lower part of this quarry face, on close examination, again seemed to me surely Dresbach. Then it was learned that the fossiliferous bed is near the top of the quarry. Not to weary you with details, I shall state the crucial facts at once. Just beneath the fossil bed a suspicious contact was observed, which, on being traced around the quarry, proved to be irregular, and at one place very much so. Moreover, touching or lying on this uneven plane we found boulders of Baraboo quartzite, moderately

rounded and up to 5 feet in diameter. Finally, the sandstone for 10 to 15 feet above this contact was shown to be thinner-bedded and less silicified than is the more massive sandstone beneath it. Evidently the two belong to distinct formations. And thus we proved that an exposure of sandstone which until then had always been regarded as belonging to a single formation in reality contains adjoining parts of two unconformable formations. In confirmation of their age assignment, I may add that the contact between the Dresbach and the Franconia sandstones is generally unconformable in Wisconsin.

UNCONFORMABLE CONTACT OF CAMBRIAN AND OZARKIAN SANDSTONES NEAR MADISON, WISCONSIN

The second problem of this kind was encountered in the vicinity of Madison, Wisconsin, where certain geologists believed they had discovered evidence that must wreck my recent determination of the relations of the Saint Lawrence formation and the Jordan sandstone, on the one hand, to the Mendota dolomite and the Madison sandstone on the other. For many years these two pairs of formations, the former having been named in Minnesota, the latter in Wisconsin, were regarded as respectively equivalent. Two years ago, however, I became satisfied of their distinctness. In fact, the Cambro-Ozarkian boundary was drawn between them, the Saint Lawrence and the Jordan being referred to the older system and the Mendota and Madison to the Ozarkian.

The evidence relied on by my friendly opponents occurs in two excellent rock cuts, one to the north, the other to the south of the city of Madison. The section in both is essentially the same, the top being formed by basal Oneota, beneath which is the Madison sandstone, while under the lowest beds seen in the cuts are shaly beds which I admitted to be of Saint Lawrence age. Now, as the Jordan intervenes in Minnesota and western Wisconsin between the Saint Lawrence and the Oneota, and the Madison sandstone in these cuts appeared to hold similar relations to the same formations, it seemed at first sight as though my contrary interpretation must be in error. But, after all, appearances in this case proved deceptive—our final conclusion leaves the formations as they were arranged by me two years ago.

Briefly, it was conceded that the shaly beds under the sandstone in the cuts belong in the Saint Lawrence, and that they do not represent the 25-foot Mendota dolomite that outcrops in bluffs on Lake Mendota and at other points in the area between the two cuts. Next, it was conceded that all of the eight known outcrops of the true Mendota are practically identical in lithologic characters and contained fossils, and that they

arrange themselves in a narrow northwest-southeast belt—probably an erosion valley—(some 50 miles long and 4 or 5 miles wide) that passes between the localities of the two cuts in which the true Mendota type of rock is absent. It was further agreed that the beds immediately underlying these Mendota outcrops vary decidedly in age from place to place; hence that the contact is unconformable, and that differential movement, emergence, and locally varying amounts of surface erosion had occurred before the deposition of the Mendota began. Finally, it was decided that the lower part of the sandstone in both of the railroad cuts represents partially eroded remnants of typical Jordan sandstone on which Madison sandstone was laid down without the intervention of the Mendota; and we found between them a slightly uneven plane of contact, the distinct nature of which, as compared with the ordinary bedding planes, is marked by the unmistakable criteria of a reworked sand deposit. Most convincing of these criteria is the relative coarseness of the quartz grains that make up the first few inches or more of the overlying sandstone—a condition resulting from washing and sifting by wave action to which the previously exposed and weathered surface of the Jordan was subjected at the time of the early Ozarkian marine transgression. In confirmation of our conclusion, it remains to be said that the characteristic fauna found elsewhere in this vicinity only in the Madison sandstone above the Mendota dolomite is confined in these cuts to beds above the break.

CONTINENTAL SEAS USUALLY SMALL AND FREQUENTLY WITHDRAWN

This brings us to one of the old conceptions that has done more to retard progress in correlation than any other. I refer, namely, to the long prevailing view of continuity of submergence of epicontinental basins and the consequent wide extent of contemporaneous marine deposition in them. It is this conception that is chiefly responsible for the common failure of geologists to recognize stratigraphic hiatuses due to emergence. The physical and faunal criteria which indicate such breaks in the process of marine sedimentation are, as a rule, readily detectable after the observer has once and for all accepted the principle of small, frequently shifting continental seas; and the true significance of the phenomena is always recognized when they have been discovered and explained and shown in the field by another.

In accord with this old conception, simulating rocks and faunas that seemed to occupy the same stratigraphic position were unequivocally correlated and commonly referred to under the name of the formation with which they were identified. This was the practice whether the correlated bed was much thicker or attained but a fraction of the thickness of the

original formation. Of course, we long ago began to correct the numerous errors that resulted from indiscriminate application of this wrong principle; and the longer we work, the more expert we become in detecting the weeds that had taken root in our stratigraphical garden. But some of these weeds have grown into lusty eye-filling plants, whose eradication, therefore, is strenuously opposed by those who believe in letting well enough alone and who object to any innovation that means change in prevailing method and practice.

This old belief and practice made us close our eyes even to patent faunal differences. A case in point is that of the basal series of the Paleozoic in the Upper Mississippi Valley—a succession of varying sandstones—which up to very recently was correlated with the Potsdam sandstone of New York. This identification was made and maintained despite the long known fact that the large faunas of the two series have not a single unquestionably identified species in common. But it is now evident through study of the fauna of the Madison sandstone—an Ozarkian deposit—that the Saint Croixan or Upper Cambrian series of Wisconsin is much older than the Potsdam sandstone, which, with the overlying limestones, makes up the typical Saratogan series of New York. On the other hand, the fauna of the Madison includes peculiar trilobites and gastropods that are unknown elsewhere except in the Potsdam sandstone and the Hoyt limestone of New York. Specifically definite faunal evidence thus has finally come to the support of my assignment of the Saratogan series of New York to the Ozarkian system. It may be of interest to note that the considerations which originally induced the conviction that the typical Saratogan is younger than the top of the Upper Cambrian in the Mississippi Valley, and elsewhere in the central and western parts of the United States, were solely of the diastrophic kind. They were concerned with probabilities of crustal movements rather than faunal data.

A largely similar case involves the Devonian-Mississippian boundary in eastern North America. This is the disputed general equivalence of the chiefly black Ohio, New Albany, and Chattanooga shales to the Upper Devonian Genesee and Portage shales, on the one hand, and to the Lower Mississippian Kinderhook series on the other. The former relation was asserted before I was born and has been the prevailing view down to the present time. However, in the past 10 years I have repeatedly denied this view, claiming, on the contrary, that the black shales of the Middle Western States are younger than the top of the Devonian in New York, from which region the universally accepted standard for the Devonian system in America is derived. Much new evidence on this problem has been acquired in the past two years. Most of this has been studied, so

that I entertain the hope and belief that I shall soon succeed in completing a work on the subject that will settle the problem finally by proving the essential equivalence of the Chattanoogan and Kinderhook series.

But I was speaking of disagreements arising from inconsistencies in method and practice. Perhaps the most troublesome are those inconsistencies which have resulted from the application of the strictly diastrophic method in one area and the purely paleontologic in another. They are distressingly troublesome because they tend without real cause to align the advocates of the two methods against each other in a blind and stubborn struggle in which the paleontologist fears for the very life of his principles. This is wrong, because our sole aim should be to win the truth without regard to whose method is adopted.

PREVAILING INCONSISTENCIES IN DRAWING THE ORDOVICIAN-SILURIAN BOUNDARY

A live instance of this kind is found in the Ordovician-Silurian boundary which was drawn in New York and in the Appalachian region generally, according to strictly diastrophic criteria. However, in Ohio and adjoining States to the west and south certain highly fossiliferous beds that are now known to correspond to unfossiliferous clastic deposits in New York, which have always been classified as Silurian, were placed in the Ordovician column. There was no intent to discredit the New York classification, for that was correctly and firmly based on criteria—of the kind now termed diastrophic—whose dominance in the case of systemic boundaries was recognized then and has never been denied since; and none knew that the fossiliferous Richmond formations finger into the barren Queenston division of the Medina series. The geologists of the day acted simply as the information then in hand demanded, and as they had observed none of the many faunal breaks now recognized in the sequence of Ordovician and early Silurian rocks exposed in the Cincinnati dome, there was no more reason to question the apparent general unity of the Cincinnatian and Richmond faunas than to suspect a time break in the Ohio section between the Richmond and the overlying "Medina" and "Clinton." Therefore, as the Richmond fossils compared much better with the Cincinnati-made conception of the typical American Ordovician fauna than they did with the succeeding Niagaran fossils, which chiefly contributed to the prevailing conception of a Silurian fauna, there was nothing else to do but to place the Richmond at the top of the Ordovician.

But now, since we have learned many facts then unknown—and since we understand that in estimating the faunal differences then supposed to distinguish the Silurian from the Ordovician no account whatever was

taken of the probably intermediate character of the fauna that must have lived *somewhere* while the great series of practically unfossiliferous Medinan deposits was being laid down in New York and Pennsylvania—what should be done? Shall we, as advocated by Grabau, Schuchert, and others, revise the New York standard and break up the practice of three-quarters of a century, a practice that was perfectly satisfactory and scientific until it ran into a prevailing, though none the less imperfect, faunal conception? Or shall we, as I believe we should, hold to the New York standard and revise instead our faunal lists, which, as every well-informed student knows, need revision badly enough?

DISCORDANT TESTIMONY OF LAND AND MARINE ORGANIC REMAINS

Paleobotanists and vertebrate paleontologists often differ from the invertebrate paleontologist in matters of correlation. Commonly, the latter places the disputed formation higher in the time scale than do the others, but in a few cases the opposite has occurred. On investigation, a definite reason for these disagreements is found in the altogether different effects of physical changes on marine and land organisms.

Land organisms naturally found the conditions that are best suited for their extension and expansion in periods characterized by predominance of sea retreat. Obviously these favoring conditions were best developed during the transition stages between each pair of geologic periods when the land areas attained their greatest expansion and their longest duration. In the very nature of the case the land organisms not only experienced the heydays of their existence during the intersystemic emergent stages of the continents, but the particular facies marking each of these must have begun in the sea-retreating closing ages of the expiring period and continued, though with decreasing representations, into the opening ages of the next period, when the ensuing revival of dominant submergent conditions induced another decided change in the composition of the land flora and fauna.

Apparently this is the reason why the evidence of land plants and animals is commonly not so clearly indicative of the exact age of beds belonging near—either above or beneath—a systemic boundary as it is in distinguishing upper and lower formations of the same system. In other words, the greater modifications of the ancient land floras and faunas seem to have occurred in the middle parts of the geologic periods and not, as is the case with marine organisms, between the close of one period and some still early part of the next.

Disclaiming all intent to discredit the value of land plants and animals in stratigraphic correlation—on the contrary, I regard their specific testimony as no less trustworthy than that of the marine invertebrates—it yet

seems to me that the evidence derived from these two or three sources should not have the same weight. It is not that the evidence of either is distinctly inferior to that of the other, but that the two kinds of data—land and marine—are necessarily more or less discordant in their respective tendencies. The one points to or centers in *emergent* stages of geologic history, the other in *submergent* stages. Consequently, in view of the fact that the time classification of geologic events is based primarily on displacements of the strand-line—in other words, on criteria furnished by marine factors—it follows that there is no such thing as a distinctly Devonian land flora having a significance corresponding, in the matter of time and duration of existence, to that conveyed by the words "the Devonian marine fauna." The latter is most typically expressed by its median, Onondaga-Hamilton facies; hence by a faunal concept marking a time when the land flora would naturally be at its minimum for the period and probably in course of adaptation to changing conditions—in transition from the facies that prevailed before to that which flourished later. The successive facies of the land flora thus must have attained their respective most typical developments in the intervals between those times when the successive marine faunal facies reached their respective high points. The two may be said to have alternated.[2]

BEARING ON THE AGE OF THE OHIO AND CHATTANOOGA SHALES

Considerations like these may largely explain the instability of the Devonian-Mississippian boundary in geologic literature. In areas containing beds rich in land plants and poor in marine fossils, the decision of the paleobotanist, providing his judgment is determined solely by preponderance of the floral affinities, would be likely to favor alliance of really early Mississippian deposits with the underlying true Devonian. The invertebrate paleontologist, on the contrary, especially in areas where marine fossils are plentiful, would be impressed by certain changes in his faunas, and therefore more likely to favor placing the doubtful beds into the younger system.

[2] The principle here brought out was submitted for critical comment to Doctors F. H. Knowlton and Arthur Hollick, the two most experienced and doubtless best qualified of our authorities on Mesozoic and Cenozoic floras. It was recognized that the test would be severe and the result perhaps indecisive, if not distinctly unfavorable, because the post-Paleozoic ages were characterized much more commonly by emergent conditions, hence by wide prevalence of land, than were the Paleozoic ages in which the submergent phases are generally thought to have predominated. On the contrary, however, I am glad to be permitted to report the result of their investigations as distinctly favoring the hypothesis. As a rule, they found that, beginning with the Permian, and thence on to the present time, the terminal floras of each period are more readily distinguishable than is either one from the nearest flora of the preceding or the succeeding period, as the case may be. For instance, the early Jurassic flora is much more easily distinguishable from the late Jurassic facies than it is from the preceding late Triassic flora. The late Jurassic flora, again, is considerably like the early Cretaceous flora.

According to the conception above outlined, the Archæopteris flora may be properly designated as the late Devonian-early Mississippian flora. The late Devonian part of its existence perhaps is distinguishable from the early Mississippian part by peculiarities of relatively small biological significance, but the facies in general is transitional in its time relations and in its most typical expression intersystemic. It follows, then, that the determination of the age of the Chattanooga and Ohio shales as Devonian or Mississippian can not be made on the basis of generalized floral relations. Nothing less than absolute identity of species and varieties should be accepted as competent criteria in this case. Preponderance of Devonian affinities should not of itself be regarded as decisive, because it may readily prove more apparent than real. The true time relations of that part of the durance of the intersystemic floral concept which succeeded the diastrophically marked boundary between the two systems by so much as the late Devonian part preceded it may not have been recognized. I believe, indeed, that this has happened in the case of the Ohio and Chattanooga shales. These plant-bearing eastern representatives of the Kinderhook have been determined as Upper Devonian on the basis of apparent preponderance of floral affinities, this mistaken interpretation being still more fastened on us by the prevailing erroneous assumption of a Kinderhook age for the Pocono of the Allegheny region and for the Cuyahoga of Ohio and Kentucky. Both of these formations (the Pocono and Cuyahoga) seem to me of approximately the age of the Culm of Europe and all three as post-Kinderhook. Under this interpretation the land flora of Kinderhook age should be much more like the Upper Devonian flora than is that of the second Mississippian epoch, which is represented in America in the Pocono and in Europe in the Culm. The Chattanoogan being, as I think, of Kinderhook age, its flora may then be expected to be closely akin to the Upper Devonian flora; and its true age is indicated less by preponderance of affinities than by the few first appearances of types marking the succeeding epochs.

Finally, in correlating minor zones of the late Devonian-early Mississippian floral or faunal sequence, nothing less than absolute identity of species and varieties should be accepted as determinative.

Revised Methods and Principles of Correlation and Classification

GENERAL DISCUSSION

So long as our leaders are expected to deliver opinions, errors of judgment and the confusion incident to correction and readjustment to accu-

mulating facts are unavoidable. However, if the science is not to die of dry-rot, but is to live and grow, we should welcome new ideas and cheerfully accept the modifications in our own method and practice demanded by the march of progress. No good can come from standing aloof, nor from setting ourselves up as defenders of the prerogatives of paleontology in stratigraphic correlation. The use and high value of fossils in correlation need no defense; but they do need to be accurately and minutely discriminated. Paleontologists should also be more careful than heretofore in avoiding the unconscious bias of previous opinions. In studying the fossils of the Ohio shale, for instance, we can not hope to reach the truth when their Devonian alliances only are pointed out, while their much stronger Mississippian affinities are wholly ignored. We must look at things as they are and from both sides, without regard to the dictates of previous training and conviction.

Again, if we consider the varying methods that have operated more or less independently in building up the present classification of sedimentary rocks, incongruous results are to be expected, for if we do not agree in methods our conclusions must necessarily differ in corresponding degree. And yet the arguments on the various sides may be, up to a certain point, entirely logical. Each contestant may be right from his viewpoint, and each may have excellent precedents for his line of reasoning.

But this does not help us to a systematic classification of geological formations. That desirable end is possible only under agreement, and the agreement must be on the matter of method, rigorously and consistently applied throughout the column.

The element of consistency in the application of the adopted methods is quite as important as any other quality, for without it a really scientific classification of the sedimentary rocks, and thus of the geological ages which they represent, is impossible. It should pertain (1) to the criteria which shall determine why and where stratigraphic boundaries of whatever grade should be drawn, and (2) to those which shall determine which combination of units is to be ranked as a group, which as a series, and which as a system. In my opinion, diastrophism, in its broadest sense, affords the only means of finally attaining a reasonably accurate and systematically constructed classification.

THE ULTIMATE BASIS OF CLASSIFICATION

Now, how shall we proceed in working out the desired end? The first step is the selection of some principle that shall guide us in determining when a geologic age has ended and a new age has begun. Obviously, such a principle should apply similarly to all the divisions of the geologic time

scale, the larger divisions up to the periods and eras being but combinations of the minor units. Concisely stated, the beginning or end, as the case may be, of a terminal unit of a stage, epoch, or period at the same time delimits the division of higher rank of which it forms a part.

Lithologic criteria and the vertical range of fossils have hitherto been employed in seeking to fix these boundaries. For many reasons the results have been deplorably indefinite, inharmonious, and often quite inaccurate. The need of some more exactly determinative and finally dominant criterion is undeniable.

Even when we have properly decided that of fossils found in some exposure of rocks one lot is of Silurian age and another of Devonian, or, to use progressively smaller units, the first is of Cayugan and under that of Manlius age, and the second lot of Helderbergian, or, more exactly, of Coeymans or possibly of Keyser age, the results still fall short of the most desired practical object of the inquiry, namely, the means employed do not suffice in determining just where in the perhaps barren interval between the accurately identified fossiliferous beds the boundary between the older and the newer series of deposits may be sharply drawn. In short, we require something that will supply the deficiencies of the purely paleontologic and lithologic methods, and thus assure greater definiteness in the delimitation of stratigraphic and time units. The means is at hand. It lies among those criteria of diastrophism that to a limited extent have always been employed, namely, those indicating alternate advance and retreat—displacement—of the strand-line.

As defined by me, the criteria of diastrophism embrace all physical and, to a certain extent, all organic phenomena implying horizontal and vertical movements of the crust of the earth; also surface deformation which may aid in the causation of such body movements. Diastrophic processes, therefore, range from the impulsive grand deformations—which may be more local than general in their visible effects—to those much more gentle yet often widely manifested movements which originate through the operation of degradational processes and serve to maintain the isostatic equilibrium of the shell. Whatever the cause of these body deformations and however manifested, they always tend in some larger or smaller degree to cause displacement of the strand-line. If the movement resulted in a deepening of one of the oceanic basins, increasing its capacity, the waters must correspondingly be universally and simultaneously withdrawn from the epicontinental basins. If, on the contrary, the capacity of the oceanic basins is diminished by sedimentation, the waters must gradually overflow the land. As in the first case, so in this, the effect on the strand-line is universal and similar on all the continents.

But there were many deformative movements—they include, indeed, most of those which affected the continental parts of the lithosphere—in which the effect on the strand-line could not have been the same, either as regards the several continents or different parts of the same continent. If the surface of a continent was warped or tilted in any way, the displacement of the strand-line necessarily differed in direction on different parts of the continent, and on the other continents at such times either advance or retreat of the coastline may have occurred. Though exact correlation of these variously manifested and relatively local differential movements of and within one or another of the "positive" parts of the lithosphere is often exceedingly difficult, the fact yet remains that all of them occasioned *some* displacement of the strand-line, and with this clue the difficulties are never insuperable.

Having accepted the periodic "displacement of the strand-line" as the dominant criterion in determining the natural divisions of geologic history, we are ready to formulate the guiding principle, namely, a geologic age is regarded as having closed when the marine waters are largely or wholly withdrawn from one or more of the epicontinental basins, the succeeding new age as having opened when the sea again began to advance in the same or in other basins. In the practical application of the principle the local stratigraphic sequence is divided at the first plane beneath any well marked faunal change that exhibits evidence of diastrophic movements and consequent displacement of the strand-line. Commonly the bounding plane is merely uneven, but in many instances the bedding planes on either side of it are more or less distinctly discordant. Such boundaries always indicate a stratigraphic hiatus or "unconformity." The time value of the hiatus is usually indicated, though as a rule not completely, by sediments laid down and preserved in other areas.

The scientific and practical advantages of the diastrophic methods are becoming more and more apparent as the tight grip of the intolerant paleozoologist is being loosened and the physical criteria indicating transgressions of the strand-line are given a fair trial. With the adoption of the diastrophic criteria in place of the purely fossil and lithologic methods of determining boundaries between deposits of distinct ages, relative certainty and definiteness of delimitation supersede uncertainty and indefiniteness. We may now put our fingers on the exact boundary that formerly remained undetected and was in fact supposed to be, if not wholly, non-existent, then at least an undiscoverable plane in a sequence of transition deposits. In many places the limits of formations, groups, and even series and systems, were arbitrarily drawn. I trust we have passed that stage in the science of stratigraphy.

RECENT INSTANCES SHOWING ADVANTAGES OF THE DIASTROPHIC METHOD

To illustrate, let me point out a few of many instances in which the application of diastrophic criteria and principles has resulted in manifest improvements. So long as we relied solely on what we believed regarding the range of certain generic types of fossils, it was practically impossible to draw a satisfactory boundary between the Lower and the Middle Cambrian in the Appalachian Valley. Admitting, as we now do, that some of the late Lower Cambrian types continued their existence in slightly modified forms into the succeeding epoch, the two series are now sharply delimitable. The case of the Cambrian and the Ordovician was even worse.

Commonly the boundary between these two systems was left undetermined, and those who did venture to draw it seldom selected the same position favored by others. Between them the boundary vacillated between the top of the Cambrian as now defined and the base of the St. Peter. As a rule, the author's decision depended on his conception of what should be called a Cambrian and what an Ordovician fauna. And the decision varied greatly according to whether he relied on the evidence of the trilobites or on that of some other class of fossils. In the Appalachian Valley the lower part of the great but locally varying series of "Knox" dolomites was stated to be of Cambrian age because it contained remains of trilobites that resembled Cambrian species. The top of the series, on the other hand, contained remains of mollusks that were thought to place this part into the Ordovician system; but under this belief several thousands of feet of intervening beds remained of undetermined age. Moreover, subsequent investigations proved that some of the mollusks referred to are much older than the supposed Cambrian trilobites, the latter being in fact of Canadian age, while some of the former are of Ozarkian age.

We may say, then, that 10 years ago the Cambrian had no recognized top and the Ordovician no bottom. Today the top of the one and the bottom of the other have been definitely determined in most areas where these rocks are exposed. This rapid progress is owing to the application of diastrophic criteria, without which it would have been impossible to show that these systems are not only sharply delimited, but that two other systems of rocks belong between them. In some places deposits belonging to the Canadian system were said to pass without break into the Ordovician, but in all of these places that I have had an opportunity to study a broken contact was found in the supposed "transition" beds.

Again, relying on supposition respecting the composition of the Ordovician fauna, we placed the boundary between this and the succeeding

Silurian system much higher in the time scale in the Ohio and Mississippi valleys than it lies in New York and Pennsylvania. In the Eastern States this boundary was properly drawn according to diastrophic criteria. In the western areas the great Richmond overlap unconformity marks the same basal limit of the Silurian. In America none of the other breaks that have been suggested as serviceable in the case is so generally and so definitely recognizable as the one at the base of the Richmond. Paleontologists should acknowledge their error in placing the Richmond fauna as older than the Oswego and Queenston sandstones of New York and not persist in it to the detriment of the science by proposing to remove the unfossiliferous representatives of the Richmond in New York, Pennsylvania, and elsewhere from the base of the Silurian to the top of the Ordovician. The removal of the Lower Medina from the Silurian would be a backward step. It would substitute indefiniteness in place of definiteness, because the base of the Lower Medina (including the Richmond) is everywhere clearly determinable, whereas the correlates and base of the Upper Medina are in many places uncertain.

Like the Cambrian-Ordovician boundary of a few years ago, so also the separation of the Silurian and Devonian in Appalachian areas containing Cayugan and Helderbergian deposits remained entirely arbitrary until the physical break between the two series was discovered. Even yet the corresponding break in the New York sections remains to be pointed out. In literature this boundary is placed differently at Manlius, Schoharie, and Rondout, and at none of these places nor in New Jersey and Pennsylvania is it drawn precisely as in Maryland. Nevertheless, and despite the considerable faunal transition, the same diastrophic break can and has been recognized at every locality between southwestern Virginia and New York where the concerned formations have been studied.

According to prevailing practice, the Devonian-Mississippian boundary is drawn variously in America. Individual authors and State surveys, too, differ greatly in this matter. In New York it is fixed at the top of the Chemung; in Ohio, Kentucky, and Tennessee at various horizons between the top of the Chemung and the top of the Kinderhook; in Iowa at the bottom, in the middle, or at the top of a gray shale which properly constitutes the basal formation of the Kinderhookian series; in southern Illinois and Missouri at some horizon in the Kinderhook above this shale. In some places Mississippian fossils were found in the Upper "Devonian black shale," and where these occurred the exact position of the systemic boundary was left undecided. And yet if the break marked by the top of the Chemung in New York, Pennsylvania, Ohio, and Virginia, and by the base of the Kinderhook in the section at Burlington, Iowa, and at

other places in the Mississippi Valley is accepted as separating the deposits of the Devonian period from those of the Mississippian, we can draw, usually with little difficulty, the same diastrophic boundary wherever marine sediments of these two systems are in contact in southeastern North America. Judging from my own experience, there are no transition deposits indicating continuity of marine sedimentation from one geologic period to the next in any area now exposed to view.

The cited instances are of highly important stratigraphic boundaries. But equally decided improvements have rewarded our efforts in revising the less important but more numerous intervening formational boundaries. The more we recognize the oscillatory character of marine deposition in the continental basins the more accurately we learn to correlate and the more exactly we mark the boundaries of stratigraphic units, whether they be of high or of low rank.

In my Revision of the Paleozoic Systems I sought to define and apply practically the principles of the diastrophic method. Because of misinformation, at other times lack of important data, the application of the principles doubtless has resulted in some—I may say even many—unhappy arrangements. Knowing some of these imperfections and expecting to find more, I am prepared to admit the appropriateness of a recent facetious paraphrasing of the title, according to which Ulrich's Revision became Ulrich's "Rawvision." It *is* rather "raw" in spots; but subequent experience has shown that the fault does not lie in the principles. The errors occur chiefly in those places where the desire to present a complete scheme necessitated undue haste in their application.

Now, let us consider certain commonly entertained conceptions—all bearing more or less directly on correlation by fossils—that seem to me in need of revision.

CORRELATION BY "MATCHING" OF FOSSIL CONTENTS

Correlation by similarity of general faunal aspect has been perhaps the most favored of methods for determining the relative ages of fossiliferous deposits. Lists of the fossils are compared and the percentage of identical and so-called "representative species" is supposed to indicate the time relations of the two or more formations. Under certain conditions, and in so far as broad stratigraphic conceptions are concerned, the idea is correct enough; but when it comes to the accurate identification of minor units of the time scale it is inadequate and indeed more likely to lead us astray than to the truth.

All, or at least most of us, I believe, accept organic evolution as an established fact. On the whole, too, it will be admitted that the evolu-

tion of faunas and floras is, and has always been, a continuous, though probably not a uniformly continuous, process. Doubtless, also, it is unnecessary to argue that the stratigraphic column, so far as it is accessible and known, contains but an imperfect record of particular stages of the developmental process. Granting all this, several considerations are readily suggested.

Beginning with a general proposition, I may say that as the faunal or floral conception ascribed to any one system or period is but a part of a continuous process of organic evolution, it is manifestly impossible to decide that the first appearance of a given species or fauna in any continental basin marks at the same time its inception, nor that its highest known occurrence in the stratigraphic column marks its extinction everywhere. Clearly, then, the determination of this collection of fossils as an Ordovician fauna, that as a Silurian, and another as Cambrian is nothing better than a more or less arbitrary age assignment of species according to recorded or personal knowledge and belief regarding their vertical or time ranges.

Much confusion has arisen through unwarranted additions to faunas commonly accepted as diagnostic of certain ages and periods. For instance, prior to the discovery that the Richmond of Ohio and Indiana is of the age of the Lower or Queenston division of the Medina in New York, lists of characteristic Ordovician fossils always included those found only in the Richmond. As previously stated, there was no other, even then, valid reason for this misassociation than the now discredited belief that the formations of the Richmond group are entirely older than the base of the Medina—yes, even older than the Oswego sandstone—with which the Silurian system, or the Upper Silurian, as it was formerly designated, began in the standard New York section.

Similarly, the large and extraordinary fishes and other fossils found in the Ohio shale in Ohio and adjoining States have for 50 years been included in the list of Devonian fossils. In fact, more than two-thirds of the Upper Devonian fish fauna as given in current literature is made up of these Ohio shale species. But I have on many occasions claimed, though seemingly without much avail, that this series of mainly black Ohio shales is younger than the Chemung of New York, and therefore that the beds and the fossils in them are not of Devonian but of Mississippian age.

Whether the future proves my contention right or wrong, the fact remains that so long as the older correlation is in reasonable question these Ohio shale fossils can not properly be included in lists of characteristic Devonian fossils.

And the geological column affords many other instances of faunas commonly credited to particular geological ages on insufficient or quite incorrect correlation data.

CAUSES OF MUTATION AND EXTINCTION OF MARINE SPECIES

Taking up another general proposition, it again seems certain that the marine faunas of the continental seas consisted almost entirely of organisms that periodically and very frequently migrated from their permanent oceanic habitats into these inland seas. Because of their shallowness and the consequent susceptibility to fatal changes in temperature to which these inland seas must have been subjected, their faunas must often have been exterminated in whole or part. However, the supply of life in the great oceanic basins was inexhaustible and presumably ever ready to replace the locally exterminated fauna.

For obvious reasons these new invasions could never be exact duplications of the immediately preceding faunal facies. Some of the previously dominant species always returned, and often the returned fauna consists almost entirely of species that had at one or another preceding time inhabited the same area. In practically all cases, however, the returned fauna differs from the immediately underlying fossiliferous zone in two respects: (1) some, and occasionally many, of the fossils of the preceding zone are absent or have become rare, and (2) one to many species that are wholly unknown in the next underlying zone have been added. Some of these added forms may recur from still lower zones, whereas others are seen here for the first time.

Under this conception of frequent local extermination of life in the shallow continental seas, and in view of the fact that the fossil remains in the deposits of these inland seas are divisible into reasonably constant specific and generic units, we are justified in concluding that the organic remains found in the successive beds and formations constitute in each case a "snapshot"-like representation of briefly enduring but specifically completed stages of the evolutionary process; also that the many intermediate mutations occurred before each of the at present accessible fossilized stages invaded the continental basins, as it were, in completed form. In other words, these unknown, and just so far unknowable as they are inaccessible, transitional modifications were accomplished in the oceanic basins during relatively longer emergent periods, in which the marine waters were withdrawn from the continental basins. These emergent periods alternated with the submergent stages, in which, of course, the stony record that is now in places bared to paleontological investigation could only have been laid down. As for the complete marine life

record, this can have been preserved only in the inaccessible floors of the permanent oceanic basins where deposition presumably continued uninterruptedly.

There seems, therefore, no ground for the belief held by some that the expansion of waters in the epicontinental basins made them areas of stimulated organic modification. If they had been, their deposits must have been filled with such a wealth of intergrading mutations as to render the efforts of the systematic paleontologist positively futile.

Proceeding, it once more seems certain that what we call fossil species and genera must have become extinct *during,* rather than *before,* the intervals that separated the periodic marine invasions of the continental seas. In other words, the final extinction of particular species or genera must, as a rule, have been accomplished in the oceanic basins. There is, therefore, no general warrant for the paleontologist's tacit assumption that the apparent and perhaps actual last appearance of a species or genus in the deposits of one continental basin or province marks at the same time also its universal extinction. We know of innumerable instances of recurrence—hence of survivals—in the same and other basins or provinces. And the same is true, though in a smaller degree, as regards earlier occurrences than were recognized in our standard of comparison.

However, under proper limitations, the first and last appearances of particular species and genera in a given province are usually excellent correlation data *within* such province; but be sure that the occurrence is the first or the last, as the case may be. Thus confined, the instances wherein these definitely located faunal appearances or invasions often fail geographically occur chiefly among those organisms, especially corals and Bryozoa, whose distribution is largely dependent on transportation of larva by shore currents. Yet, so far as they go, these very animals are of extraordinary value in correlation, for distribution by currents insures rapidity of migration and corresponding accuracy of time determinations based on their testimony.

But I am in danger of being misunderstood. My reference to the areal limitation on the one hand and the extraordinary correlation value on the other of organisms owing their distribution to current action includes only those that are free-swimming in their larval stages and bottom dwellers thereafter. It does not include the truly pelagic forms, like graptolites, many pteropods, and certain cephalopods. For some reason—perhaps because of greater stability of environmental conditions—these pelagic organisms commonly seem to have been less mutable, hence longer lived as species and genera, than other marine animals that existed under more changeable conditions.

Yet, despite this fact, pelagic animals as a class are the most valuable of all for intercontinental correlations. Indeed, when it comes to the identification of Lower and Middle Paleozoic horizons across great oceanic basins like the Atlantic and the Pacific, only the graptolites afford reasonably accurate results. The ammonoid cephalopods are similarly useful in recognizing later horizons. Both types owe their advantage to complexities of structure in which relatively trivial modifications are certainly if not readily determinable. The pteropods also might share in this correlation value were it not for their relatively simple construction.

GENERIC ALLIANCES AMONG PELAGIC ORGANISMS INSUFFICIENT TO ESTABLISH CONTEMPORANEITY OF DEPOSITS

However useful in correlation these pelagic animals may be, experience has shown that where exact results are required mere generic alliances are quite insufficient to establish contemporaneity. The genera commonly prove to have endured too long to be of exact value in detailed correlation. The case of the Utica fauna is an excellent illustration:

In 1847 Hall identified all dark graptolite-bearing pre-Niagaran shales then known in America as belonging to the Utica age. We will overlook the fact that he included at this time even the Georgia slate, which is now classified as Lower Cambrian; likewise the Levis shale of Canadian age. Neither of these formations was correlated with the Utica in 1862. But on account of the presence of supposedly the same graptolites, the Normanskill and Magog shales in eastern New York and Quebec, the Canajoharie shale in the Mohawk Valley, the Collingwood shale in western Ontario, and the Maquoketa shale in the Mississippi Valley were for a long time after 1862 regarded as of Utica age. In the past 10 years, however, detailed stratigraphic investigations, coupled with a closer study and consequent discrimination of their respective fossils, have shown the Normanskill to be of Upper Chazyan age, the Magog, Canajoharie, and Collingwood of respectively Lower, Middle, and Upper Trenton age—all four, therefore, of greater age than the typical Utica shale—while the Maquoketa was found to be much younger, being an early Silurian—Medinan—formation.

In the present relatively refined state of knowledge respecting the character and distribution of graptolites the inadequacy of generic alliances of graptolite faunas in making detailed correlations is fully recognized. Besides, it is no longer necessary to depend on such uncertain evidence, because we now recognize many closely drawn species and varieties in widely separated localities; and these minute identifications enable us to correlate graptolite zones with unquestionable certainty.

Referring to another general idea, it seems no less certain that circumstances must have often arisen that tended to exclude certain species, or even whole faunas, from continental basins to which, under preceding or succeeding more favorable conditions, they enjoyed free access. These changes in physical conditions were responsible for two facts that are exceedingly important in correlation by faunas: (1) That most provinces were at times invaded by waters of different oceanic basins, each at such times bringing with it the fauna peculiar to its own realm, the others being excluded; (2) they occasioned the recurrences of species and faunal aggregates—that source of much trouble in the past and now a constant menace in correlation by marine faunas. Instances are multiplying, and some of the best have not been published. I may mention two that have been proved in the past year. Both are earlier occurrences of faunas than had been known before.

FAUNA OF THE MENDOTA DOLOMITE, AN EARLY OZARKIAN FORMATION

The first of these recurrences affects the peculiar fauna of the Mendota dolomite of southern Wisconsin. As now known, the true Mendota fauna comprises a total of 28 species; 16 of these are gasteropods, 3 pteropods, 6 trilobites, and 3 brachiopods. In general aspect the fauna is decidedly Ozarkian, but with some reminders of Upper Cambrian species. The latter, however, constitute a smaller proportion of the whole than is apparent in the fauna of the succeeding Madison sandstone.

We are indebted to the efforts of Dr. Samuel Weidman and Mr. T. F. Thwaites, of the University of Wisconsin, for the discovery of a dolomitic ledge in the Saint Lawrence formation that in both its lithologic character and faunal contents closely resembles the true Mendota dolomite. This ledge is developed to the west of Madison in hills bordering the valley of Black Earth Creek, between Black Earth and Mazomanie, Wisconsin. It should be mentioned, further, that the bed lies in the middle part of the Saint Lawrence, beneath the *Dikelocephalus minnesotensis* zone, and that the Saint Lawrence is the second formation beneath the top of the Cambrian, as now defined in the Upper Mississippi Valley. The Jordan sandstone lies between the Saint Lawrence and the overlapping and consequently varying base of the Ozarkian.

So far as collected, the fauna of the Black Earth dolomite, as this Cambrian bed may be provisionally designated, consists of 13 species. Ten of these are strikingly like species found more or less abundantly in nearly every exposure of the fossiliferous part of the true Mendota; in fact, the fossils from these two zones are so much alike that if the probability of their distinctness had not been suspected the Black Earth species

would scarcely have been distinguished from their Mendota congeners. Under the circumstances the specimens were very carefully prepared, and then as carefully compared with collections from six different exposures of the typical Mendota. The result of these comparisons shows that whereas no structural differences whatever could be detected between the specimens of the same species from the various Mendota localities, those from the Black Earth dolomite proved in every instance to be distinguishable by inconspicuous, yet constant, differences.

It is to be observed, however, that in both instances the specimens are preserved as casts of the interior, and if these can be distinguished we may believe that more perfect specimens would exhibit other perhaps more important differences. But in their present condition the molluscan remains from the two zones are distressingly similar.

But it is not to be overlooked that these Mendota-like fossils in the Black Earth dolomite are associated with three fossils that, so far as known, have no representatives in the true Mendota fauna. These, then, are for the present the real guide fossils for the Black Earth dolomite zone.

A HELDERBERGIAN INVASION OF THE ONONDAGA CORAL FAUNA

The second instance concerns the presence of a coral fauna of 31 species in the midst of beds holding a normal late Helderbergian—New Scotland and Becraft—fauna. The beds referred to occur at and in the vicinity of Big Stone Gap, in southwest Virginia. They lie unconformably on limestones of Cayugan age and are followed unconformably by black shale of Genesee or Portage age. Some years ago Professor Schuchert determined their age to be Coeymans and New Scotland, his opinion being based on the brachiopods contained in the small collections made by him at Big Stone Gap. Somewhat different views were entertained by Williams and Kindle about the same time, but they were not sufficiently definite to require quoting here.

In 1912, however, Doctor Kindle made larger collections, particularly from one of the coral zones. Being impressed by the very striking Onondaga aspect of the coral fauna, this author assigned the upper part of the limestone unreservedly to the age of the Onondaga. The brachiopods and other fossils found beneath and in association with the corals were not specially considered by Doctor Kindle.

I became interested in the problem through the necessity of reporting officially on the age of similar collections made by Federal Survey geologists engaged in the preparation of geological maps in adjacent areas.

Finding it impossible to reach a definite conclusion from the conflicting fossil data, I made a special visit, accompanied by Mr. T. E. Williard, to Big Stone Gap in October last, hoping that a study of the stratigraphy might throw some light on the problem.

Briefly stated, these investigations enabled me to divide the 150 feet of limestone between the Cayugan below and the base of the overlying black shale series into eight zones. It was established further that the corals are of one fauna; that they occur as scattered colonies in zones III and IV; more abundantly and locally in reef-like associations in zone V; again rather abundantly, but in scattered colonies, in the upper part of zone VI, and finally in great abundance at the top of zone VII. Zone VIII is without the corals and was observed in only one section, the Upper Devonian black shale being in contact with zone VII in the others. In zone I also the coral fauna is absent, the 31 species of fossils collected from this zone being, moreover, a very typical New Scotland association. Overlying it is zone II, a 2-foot bed of conglomeratic sandstone.

Associated with the corals and occupying the beds between and above the three main coral-bearing beds are many other fossil remains that clearly belong to a single slowly modifying fauna. The general aspect of this fauna is decidedly late Helderbergian, with at first a few and finally a considerable percentage of species known elsewhere to range upward into the Oriskany. But the proportion of these Oriskany fossils is no greater than is observed in the late Helderbergian deposits of Maryland and New York. Besides, they include none of the really diagnostic species of the Oriskany, such as occur abundantly and in associations indicating both the Lower and Upper Oriskany at localities less than 50 miles east of Big Stone Gap. Schuchert, therefore, seems to have been fully warranted in claiming absence of Oriskany deposits in the Big Stone Gap sections.

Now, as to the large coral fauna found in association with these Helderbergian fossils. No one can justly deny their striking resemblance to the Onondaga corals found at the Falls of the Ohio. But critical comparison with excellent suites of the latter showed that, with possibly a single exception, none is exactly like its representative in the typical Onondaga limestone. That these corals belong to an earlier age is further corroborated by the fact that none of the associated Helderberg and Oriskany species have ever been found in unquestionable Onondaga limestone.

Taking all the facts into consideration, we must, then, conclude that a dangerously similar phase of the Onondaga coral fauna existed and in-

vaded southwestern Virginia already in late Helderbergian—evidently Becraft—time.

FAUNAS OF DISTINCT MARINE PROVINCES DIFFER IN COMPOSITION AND SEQUENCE

Experience has definitely shown that the foregoing generalizations are well founded. Incontestible evidence has forced the admission that in both the composition and the sequence of fossil faunas, and to a considerable extent also in their vertical or time ranges, the records in the different provinces vary more or less decidedly. To meet this condition it has become necessary to compile faunal standards for each province. Within the borders of each province the percentage method of estimating faunal, consequently time relations, is still useful; but even in these cases the result of such direct matching of faunas should not be accepted without verifications by other criteria. That would be allowable only when the comparison shows detailed specific agreement.

To illustrate: We know of contiguous formations containing closely simulating faunas that on investigation proved to be separated by an unconformity. This structural relation at once suggested a much greater difference in age than their contiguity and faunal similarity indicated. Subsequently it became evident that the likeness in fossil contents meant only that the two formations derived their faunas from the same oceanic realm.

Fortunately, in one of the cases referred to, the true relations of the formations are shown in a neighboring area, where a wedge, reaching thousands of feet in thickness, is introduced between them. Moreover, in the latter area the intercalated formation contains a large fauna so radically different as to immediately suggest a widely distinct age. However, this is not the case, the striking difference having no further significance than that the simulating lower and upper faunas invaded the area from the Gulf of Mexico, whereas the altogether different intervening fauna was developed in the middle and north Atlantic.

When it comes to correlating formations in different provinces, all strictly paleontological criteria depending on comparisons of general faunal aspects fail as a rule to give lasting results. The best exceptions to the rule are those furnished by formations and faunas which transgress from one province to another. The exceptions include the widely ranging, current-borne, pelagic faunas which, however, because of the usual absence of transcontinental currents, seldom invaded the interior continental basins. But they do not include the so-called "cosmopolitan" bottom faunas, for none really deserving this designation ever existed.

The aggregate range of a few broadly conceived species of the latter kind finally became world-wide, but their geographically separated fossil occurrences commonly are easily distinguishable and seldom, if ever, so nearly contemporaneous as to be of practical value in exact stratigraphic correlation.

Correlation of Paleozoic formations in distinct provinces seems especially difficult, and the difficulties seem no greater when the provinces are on different continents as when they are on the same continent. Indeed, I have found it easier to establish time relations between Paleozoic formations in Europe and parts of North America than between those of the Ohioan and the Cordilleran provinces in the United States. Fortunately a few of the widely transgressing faunal horizons are recognizable in the two regions. The task, therefore, is not hopeless, for with these datum planes the relations of the intervening parts may be satisfactorily determined by means of the physical criteria of diastrophism.

The difficulties encountered in correlating by invertebrate faunas are less formidable when it comes to the Mesozoic and Cenozoic formations, for here we have less and less to do with diversely originating marine deposits in far inland areas. Besides, though the matching of the younger Atlantic and Pacific faunas is perhaps no less unsatisfactory, we need not at once call on the physical criteria. This final recourse is deferred until the evidence of the land animals and plants, which became prominent in the meantime, has been exhausted. The land organisms bridge the land gaps between the marine invasions and should be accepted as serving the same purpose in correlating deposits of distinct marine provinces as that performed by the widely transgressing marine faunas.

EXAMPLES SHOWING TENTATIVE NATURE OF CORRELATIONS BASED ON SUPPOSEDLY CHARACTERISTIC GENERA

Now permit me to mention a few of many instances tending to show the arbitrariness—consequently the probable tentativeness—of age relations generally credited to supposedly characteristic fossils, particularly of the grade of genera.

Formerly mention of the Olenellus fauna was only another way of referring to Lower Cambrian remains. Now, though the fact has not yet appeared in the textbooks, it is recognized that an excellent expression of this fauna persisted into Middle Cambrian time.

Similarly the fauna containing trilobites of the genus Crepicephalus was thought to be confined to the Middle Cambrian, but this also proved

wrong when the beds containing the best development of the genus were found to be of Upper Cambrian age.

The peculiar cephalopod, Gonioceras, long believed to indicate a late Black River age, is now known to range downward almost to the base of the Chazyan series.

And so it goes with other genera as we pass up the geological column. Several instances, known to me for many years, but only recently published, are concerned with the much-discussed Devonian or Mississippian age of the Bedford shale of Ohio. Three genera of brachiopods—Pholidops, Delthyris, and Nucleospira—cited in paleontological literature prior to 1914 as confined to beds beneath the top of the Devonian, are represented by one or two species each in the Bedford. This fact was mentioned in 1912 by a prominent paleontologist as indicating the Devonian age of the formation. Evidently he was not aware that the Mississippian contains more species of Delthyris than are known to occur in the Devonian, and that Nucleospira is about as well represented in the younger system as in the older. As for Pholidops, the oldest known species of this persistent genus is found in the lower part of the Ordovician; and the survival of the generic type into the Bedford is of no more significance in deciding the age of this formation than attaches to the long-known presence of Leptæna, another common Ordovician, Silurian, and Devonian genus in the Burlington limestone.

EXPANSION OF THE VERTICAL RANGE OF GONIOCERAS

To more clearly illustrate the point that it is desired to make regarding the uncertain value of generic alliances in correlation, the case of Gonioceras may be given in some detail.

For more than 50 years we have known that Gonioceras is to be found at Murfreesboro, Tennessee. But this Tennessee occurrence—perhaps largely because it is found there with an Hormoceras that was identified with *Hormoceras tenuifilum,* the constant associate of *Gonioceras anceps* in the original New York localities—was accepted as establishing the Black River age of the limestone at Murfreesboro. It was only after the Lowville limestone, which underlies the *Gonioceras anceps* zone in New York, was recognized in Pennsylvania and thence traced southwardly into Tennessee, where it lies far above the beds containing Gonioceras and Hormoceras at Murfreesboro, that we began to see how widely different in age are the New York and Tennessee occurrences of these cephalopods.

But this was only the first stage in the revision of prevailing belief regarding the age indication of Gonioceras. Ensuing stratigraphic in-

vestigations in east Tennessee showed that the contact between the Lowville and the Stones River group, of which the Murfreesboro limestone constitutes the lowest of four formations, represents a hiatus that opens eastwardly to make room for another thick group of sediments. The intercalated group—the Blount group of my classification—reaches an aggregate thickness of more than 3,000 feet of limestone and shale, a part of which corresponds in age to the Upper Chazy of New York.

In this manner the range of Gonioceras, formerly believed to be represented by specifically indistinguishable occurrences in widely separated places and to indicate a Black River zone whose maximum thickness in New York is less than 10 feet, has been expanded to cover a thickness of chiefly limestone deposits aggregating approximately 4,700 feet. This conclusion, I am glad to say, has since been largely verified by the discovery in New York of both generic types in two formations—the Chazy and Pamelia limestones—that are much older than the "7-foot tier" of the Watertown limestone in which these cephalopods were originally found.

It should be noted that these extensions of vertical range are not based so much on new discoveries in beds previously known to be younger or older as on corrections of previous opinions regarding the age of some of the deposits containing them. It is *this* fact that illustrates the folly and danger to successful correlation of the common practice of assuming knowledge respecting the range of fossil genera that actually we do not possess. Experience clearly discourages the assumption that genera, or even subgenera and broadly conceived species, will stay in the stratigraphic limits to which they have been assigned.

And yet, up to very recently and I fear even to the present time, paleontologists have accorded a greater value in correlation to affinities of generic rank than to those of a specific grade. The idea is used in a recent paper by Dr. George H. Girty, who, in advocating the Devonian age of the Bedford shale of Ohio, emphasizes the fact that the "Carboniferous affinities of certain Bedford fossils are *specific,* while the Devonian ones are *generic.*"

If there is any logical reasoning back of this proposition, I fail to see it. There might be some roundabout defense of the principle in the case of first appearances, but certainly none where the further range and final *extinction* of genera and species are concerned. Its most obvious fallacy lies in disregarding the large element of chance and probability. Thus we may readily conceive of the possibility of a variety or even of a species becoming extinct at times of stress not only locally but generally. But a

genus has as many more chances to survive as it comprises other contemporaneous species.

We may conclude, then, that generic alliances are of very doubtful—perhaps it would be better to say indefinite—value in correlation. Properly checked by other criteria, such identifications are useful in approximate correlations between distinct provinces. Within the same province, however, where more definite results are desirable, they are to be used only when organic remains are few, or when the species as well as the genus is identified.

For much the same reasons *stages of evolution* are often of uncertain and always indefinite value in correlation. We do not know how fast or slow evolution progressed. Certainly the *apparent* rate varied greatly in different instances and at different times. Nor can we always decide whether so-called primitive characteristics are really so chronologically. Besides, a great deal of information is required before we can be sure that the presence of "primitive characters" are not due to reversion or arrested development.

In this connection I am reminded of an instance wherein a paleontologist of the highest standing established a new genus on the ground that its genotype possessed structures indicating a more advanced stage of development than prevailed in the half dozen other species left in the older genus to which it also had been referred. Unfortunately, however, stratigraphic investigations proved that the supposedly more mature type was really much older than the allied other species which were thought to be the more primitive of the two.

As a rule, I doubt whether correlation by stages of evolution is a dependable criterion except in such cases in which the life history of a genus or family is reasonably well worked out. Then, perhaps, we might go so far as to decide that a stratigraphically unplaced new species which has been found to agree best with species prevailing, say in the Hamilton stage, is of Devonian age. But even then I should regard the assignment as provisional.

AGE DETERMINATION SOLELY BY PERCENTAGE OF SPECIES KNOWN ELSEWHERE

Authors sometimes decide the age of formations by means of faunal comparisons confined to those species which the unplaced formation holds in common with standardized formations elsewhere. The other species of the fauna, even though they comprise the greater part of it, are wholly ignored. An example of this method is contained in a manuscript re-

cently read by me, in which the writer endeavors to show that the McKenzie, a post-Rochester Silurian formation that is widely distributed in the middle third of the Appalachian Valley region, is of late Niagaran and not of early Cayuga age, as some have claimed.

He begins his argument with the statement that the fauna of the formation, so far as known to him, comprises a total of 53 species. Of this number 37 are said to be new and confined to the formation in question. The remaining 16 species are referred more or less definitely to previously described species. The 37 new species, being unknown elsewhere, he dismisses as having no bearing on the age of the formation. Proceeding, then, with an analysis of the identified old species, he finds that 9 have "distinctly Niagaran affinities," 3 have Cayugan and Helderbergian affinities, 3 are widely ranging Silurian species, and, finally, 1 that has so wide a range that it may be set aside as "not significant." On account of the preponderance of the Niagaran affinities thus indicated by the previously described species, the formation is determined to be of Niagaran age.

Carried out in the usual manner, wherein the fossils are identified with rather loosely conceived specific units, this method of correlation can not be too strongly condemned. It would be admissible and defensible only when the identifications are of minutely discriminated mutations. And in that case the same bed would not contain both distinctly Helderbergian and unqualifiedly Niagaran fossils. In the instance referred to, I know that the 9 fossils cited as indicating distinctly Niagaran affinities were not identified by those biologically unimportant peculiarities of surface marking which alone are reliably indicative of contemporaneity. In fact, most of them can not be so accurately identified because their preservation is inadequate for the purpose. Moreover, even in the state of preservation in which they are available, these so-called Niagaran fossils suggest enough of difference from their Niagaran allies to cause other students of the fauna not only to question the asserted identities but in most instances to deny them.

Further, it is important to note that all of these Niagaran species are represented by unquestionable descendants in post-Niagaran—especially Helderbergian and Oriskany—rocks. They must, therefore, have existed somewhere during the intervening Cayugan epoch. In view of the fact that their respective stocks continued to exist into the Devonian—modifying, of course, slowly in the meantime—is there any warrantable objection to viewing these 9 "Niagaran" species of the McKenzie as representing Cayugan stages in their development? This suggestion is further

supported by the fact that included in the 16 species considered by the writer of the paper mentioned 3 are identified with species known elsewhere only in Cayugan or Helderbergian deposits.

But why deny consideration to the 37 new species that really make up the bulk of the fauna of the formation in question? Surely they have some bearing on the problem. Why not determine the relative nearness of their relations to their Niagaran allies on the one hand and to their congeners in the Cayugan and Helderbergian faunas on the other? It seems a careless procedure to ignore this additional and perhaps most important means of attaining the truth.

It happens that I know the fauna of the McKenzie formation rather well. The new species in it are underrated at 37, the number reaching at least 60. The Ostracoda alone make up more than one-half of this number, and only 5 of these are at all closely allied to Niagaran species. On the other hand, the same species, as well as all the other new Ostracoda of the McKenzie, are exceedingly like species found abundantly in overlying Cayugan and Helderbergian formations. It is indeed fairly questionable if more than half of the McKenzie Ostracoda are specifically distinguishable from their later representatives. On the other hand, it has been positively determined that at least 50 per cent of the species of Ostracoda found in the overlying Wills Creek formation are practically identical with McKenzie species.

Judging, then, from the known distribution of the Silurian and Devonian Ostracoda, counting the new species as well as the old, the fossils of this class in the McKenzie formation are decidedly indicative of a post-Niagaran age.

Study of the other classes of fossils in this formation similarly led me to the conviction that, taken as a whole, they resemble Cayugan and Helderbergian species more than Niagaran. Whether this be so or not, the fact remains that the bulk of the fauna as now known is distinct from all known Niagaran faunas. This of itself indicates that it is of later date, even though the differences are in large part due to the fact that whereas most of the known Niagaran faunas in America are either of southern or boreal origin, the Cayugan and early Helderbergian faunas in the Appalachian region invaded from the Atlantic.

The Lower Clinton fauna in the Appalachian region consists wholly of Atlantic derivatives. The same is true also of the Appalachian upper or Rochester Clinton fauna, except in central New York, where the Atlantic fauna interfingers with bryozoan faunas that invaded from the southwest. In Maryland and Pennsylvania, therefore, the Rochester zone contains

many species of Atlantic origin that are absent in western New York and lacks even a greater number of the species of the southern region that are abundant at the type locality of the Rochester and in corresponding deposits in the Ohio Valley.

Because of its bearing on correlation, it is highly important to note that practically all of the fossils of the McKenzie that have "Niagaran affinities" are allied to members of the Atlantic fauna that invaded the north Middle Appalachian region during the Rochester age. Those that have relatives also in the more western Niagaran faunas are types that were then common to both the southern and the northern Atlantic realms. The presence of these Atlantic-Niagaran types in the McKenzie, therefore, is not particularly diagnostic. Moreover, as these types are known to have maintained their existence in the north Atlantic through the Cayugan into the Devonian, invading the Appalachian troughs when opportunity offered, and as their McKenzie representatives are at least as different from their positively determined Niagaran facies as from their late Cayugan and Helderbergian descendants, it seems reasonable to conclude that they are post-Niagaran in age.

But there are two other facts that must be taken into account in deciding the age of the McKenzie formation, and both are in harmony with the trend of the evidence already presented. First, the Lower Cayugan formations in New York are almost barren of normal marine faunas; second, the Upper Niagaran deposits which are well developed in western New York pinch out rapidly in going eastward, being entirely absent in the eastern third of the State. The Silurian sequence in central to eastern New York, therefore, is (1) Medinan, (2) Clinton group of the Niagaran, (3) hiatus corresponding to the Upper Niagaran or Lockport group, (4) Cayugan deposits resting on the Clinton, and (5) one or another of the Helderbergian formations following the "Tentaculite" or typical Manlius limestone. The oscillating movements which caused the differences observed in comparing the stratigraphic sequence in western and eastern New York doubtless similarly affected the areas to the south in Pennsylvania and Maryland.

The diastrophic evidence thus appears to support the testimony of the fossils as indicated by minute comparisons involving the whole fauna and not merely the small part that is loosely identifiable with described species. Taking into consideration other factors that limit the possibilities upward, but which it is unnecessary to discuss here, there is but one possible conclusion, namely, that the McKenzie formation of Maryland and southern Pennsylvania is early Cayugan and not late Niagaran in age.

This instance is discussed in considerable detail because it affords a good illustration of the incompetence of faunal correlations that take into account only the described species, and at that without pretending to identify them with absolute certainty. It also illustrates the general similarity of successive faunal invasions from the same oceanic realm in contrast to the obvious distinctness of directly superposed fossil faunas that invaded from different oceanic realms.

Proper use of Fossils in Correlation

In many—but why not confess the fact and say in most—instances of revised opinion regarding the range of fossil species and genera the suggestion, and often the proof, came first through detailed stratigraphic investigations. These put the paleontologist on the defensive and often forced the admission that fossils previously identified as well known species are in fact easily distinguishable. I am glad to say such humiliation is less likely now than heretofore, because, as the burnt child shuns the fire, so may *we* escape by *closer discrimination of fossils at the outset.*

And therein lies the salvation and the final justification of correlation by means of fossils. But remember, the function of the fossils is to identify *horizons* and *not to decide how the division of geologic time into epochs and periods is to be carried out.*

The only kind of fossil evidence that has a definite and unimpeachable correlation value is that afforded by the identification of relatively trivial biological differentiations. In the very nature of things *these,* be they called varieties or mutations, *must be* trustworthy indices of contemporaneity. If the basic principle of the idea is apparent, then the reader will see at once also the truth of the following qualifying or at least kindred principle, namely, *the inherent correlation value of a fossil species is in proportion to its complexity of structure, being greatest when the complexity is in parts which are structurally unessential.*

On the contrary, simply constructed organisms, with few characters that might be preserved in the fossil state—as, for instance, a shell with rounded, low conical form and smooth or but simply marked surface—these are of little value, because such types usually persisted through long ages, and their numerous successive occurrences are often so much alike that the human perceptions are incapable of distinguishing them.

The differentiations regarded as particularly valuable are such as pertain to the surface marking or ornament of shells of mollusks or brachiopods; granulation and peculiarities of venation of the test of trilobites

and ostracods, or, better still, nodes in some cases and pits in others on the middle of the head and on free cheeks; or spines on the head, tail, and pleura which occur in endless variety of number, length, and arrangement; in the case of the conodonts and annelid jaws, which often are found in beds otherwise nearly barren, excellent criteria of this kind are offered by peculiarities in the number, arrangement, length, and thickness of the denticles. Though any of these features may be repeated more or less precisely in other species of the same genus as well as in other genera of the same class, combinations of two or more minor peculiarities are commonly notable by which the several occurrences may be distinguished, and *these combinations are never exactly reproduced.*

Extravagance in development of any feature could not have lasted long; hence species so distinguished are reliable horizon markers. Even the Ostracoda, referring particularly to the more or less complexly marked Beyrichidæ and Cytheridæ, are of great value in identifying horizons. Valves and entire carapaces of these small crustacea often are exceedingly abundant, widely ranging, and commonly better preserved than are the remains of other classes of fossils. I found them most useful and reliable in correlating the Silurian and early to Middle Devonian formations in the Appalachian region.

Composite types like the Bryozoa, which have many individual and colonial characters, are especially useful, because biologically unimportant differentiations may yet, and commonly do, produce positively recognizable combinations. The Bryozoa have been of the greatest help in correlating Ordovician and Silurian horizons; and now the detailed studies of Canu and Bassler are proving them to be equally valuable in establishing the time relations of Tertiary deposits in the southern Coastal Plain of the United States.

By the recognition of such minute structural differentiations we actually identify geological horizons, for it seems practically impossible that the same combination of minor and major biological characters can have existed either very long or more than once. In my opinion, therefore, the occurrence of a single finely drawn variety in two or more widely separated places—be they in the same province or not—is a more trustworthy indication of the contemporaneity of the beds containing it than would be any quantity of the indefinite testimony afforded by generic alliances.

Summing up, the relative finality of our paleontological work in correlation depends (1) on how closely we discriminate our fossils, (2) on a proper appreciation of the relations of the evidence of marine animals to

that of land organisms, and (3) on a similar understanding of the relations of the physical criteria of correlation to those based on organic evidence. But the boundaries between the deposits which we identify by these means are defined only by the physical criteria of displacement of the strand-line.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

CORRELATION AND CHRONOLOGY IN GEOLOGY ON THE BASIS OF PALEOGEOGRAPHY[1]

BY CHARLES SCHUCHERT

(*Read before the Paleontological Society August 3, 1915*)

CONTENTS

Rise of Chronology

CONCLUSIONS OF THE EARLIER GEOLOGISTS

Geologic chronology had its beginning in north Germany in the superposed formations of Lehmann (1756) and Füchsel (1762), which are now included under the terms Permian and Triassic. Werner (1775-1817), whose knowledge of the geographic distribution of formations was ex-

[1] This is the third of four papers read at the summer meeting of the Paleontological Society at the University of California, August 3, 1915, in the symposium entitled "General consideration of paleontologic criteria used in determining time relations."

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ceedingly limited, did not hesitate to say that they were universal, and that what was true of Saxony held for the entire world. This very erroneous idea of universal formations was destined to sway all subsequent stratigraphy, and it can not be said that geology has yet freed itself wholly of Werner's dictum. Formations as now understood are more or less localized deposits of sediments or solution materials, and even in the sense that the term was understood by Werner—that is, as of period value—it is not true that they are universal. To emphasize this, we need only contrast the remarkably extensive Paleozoic marine sequence of North America with the almost complete absence of such a record in Africa south of the Sahara Desert.

The first great advance in a determinable stratigraphy came with William Smith (1799-1801), lovingly nicknamed "Strata Smith," who clearly pointed out that formations are characterized by definite kinds of fossils that do not occur in other horizons. The time value of extinct organisms was put into still better working order by Cuvier and Brongniart (1808-1811), whose work was based on that wonderfully interesting Tertiary sequence of the Paris basin—a series of interbedded marine and continental deposits. However, the full value of fossils as horizon markers was not appreciated by them, because the theory of evolution as taught by their associate Lamarck (1801) was set aside by them for that of cataclysms, or the periodic destruction of all life and the re-creation of similar but different successive floras and faunas. The once almost universally accepted theory of special creations was long combated by Lyell, and began to break down through the teachings of the French geologist, Beaumont (1852), who pointed out that the periodic destruction of life was due to the sudden origin of mountains. In this explanation arose the significance of unconformities, and gradually it was learned that the cataclysms were local and not universal in nature, though the full value of fossils as horizon markers was seen only after the appearance of Charles Darwin's great classic, "The origin of species" (1859).

During the nineteenth century nearly all geologists believed in the slow and continuous emergence of the continents, and in North America the dominant teaching was that of Dana, who held that the Paleozoic sea gradually withdrew from North America, leaving in its wake progressively younger, irregular rings of fossiliferous sediments that were deposited around the older Laurentian nucleus. This theory did not break down, even after it was shown that the nucleus could not have furnished all of the sediments of the many formations, and one can not say even now that the hypothesis of a continuous Paleozoic sea has vanished from our text-books. However, as early as 1845 Murchison called attention to

the fact that the Permian of Russia is constituted of three series of strata—two zones of mechanically made deposits separated by a limestone—just as is the Triassic of north Europe. The great significance of this announcement was not appreciated by the geologists of the time, and it is probable that even its author did not see its full import. John Strong Newberry, however, read the statement, and after 1860 proposed the theory of "cycles of deposition," an idea which he came to hold largely through his explorations in 1857-1858 with Lieutenant Ives up the Colorado River of the West, the region that has inspired so many American geologists, and in 1874 he stated clearly the theory of periodicity of sea invasion. Although we no longer hold so firmly to the theory of cycles of sedimentation, out of it has grown much of our modern conception of periodic diastrophism. In turn, Newberry's writings reacted on the Irish geologist, Hull, who in 1862 applied the theory mainly to the Carboniferous sequence, and in 1872 Godwin Austen directed attention to the fact that "the marine series is again and again interrupted, over large areas, by continental deposits, like the Old Red sandstone, for instance, the Coal Measures of the Carboniferous system, and the fresh-water deposits of the Weald."

These ideas came to fruition in Suess (1885-1888), who did not think that the periodic invasions of the sea were necessarily caused by the movements of the earth's crust as exemplified in the making of great mountain ranges, for, after all, these are comparatively local and culminate rapidly, while the transgressions are far more widely spread and decidedly slower in attaining their climax. There are, therefore, according to him, "independent movements of the sea—that is to say, changes in the form of the hydrosphere." In these movements lies the valuable fact of world-wide spread similar events and the possibility of employing almost everywhere the same terminology relating to periods and eras. This general correlation would have been impossible if the limits of the periods had not been drawn by natural processes simultaneously in operation over much of the earth's surface.

PERMANENCY OF CONTINENTS AND OCEANS

Most of the older geologists held that the continental and oceanic areas had repeatedly changed places, and Lyell taught that all parts of the ocean bottoms had been land. James D. Dana was the first to assail this conclusion, and shortly after his trip around the world with the Wilkes Exploring Expedition announced, in 1846, that the continents and ocean basins have been practically permanent. That the continents are on the whole permanent is proved by the fact that their marine deposits are almost entirely of shallow seas. Where deep-sea formations occur they

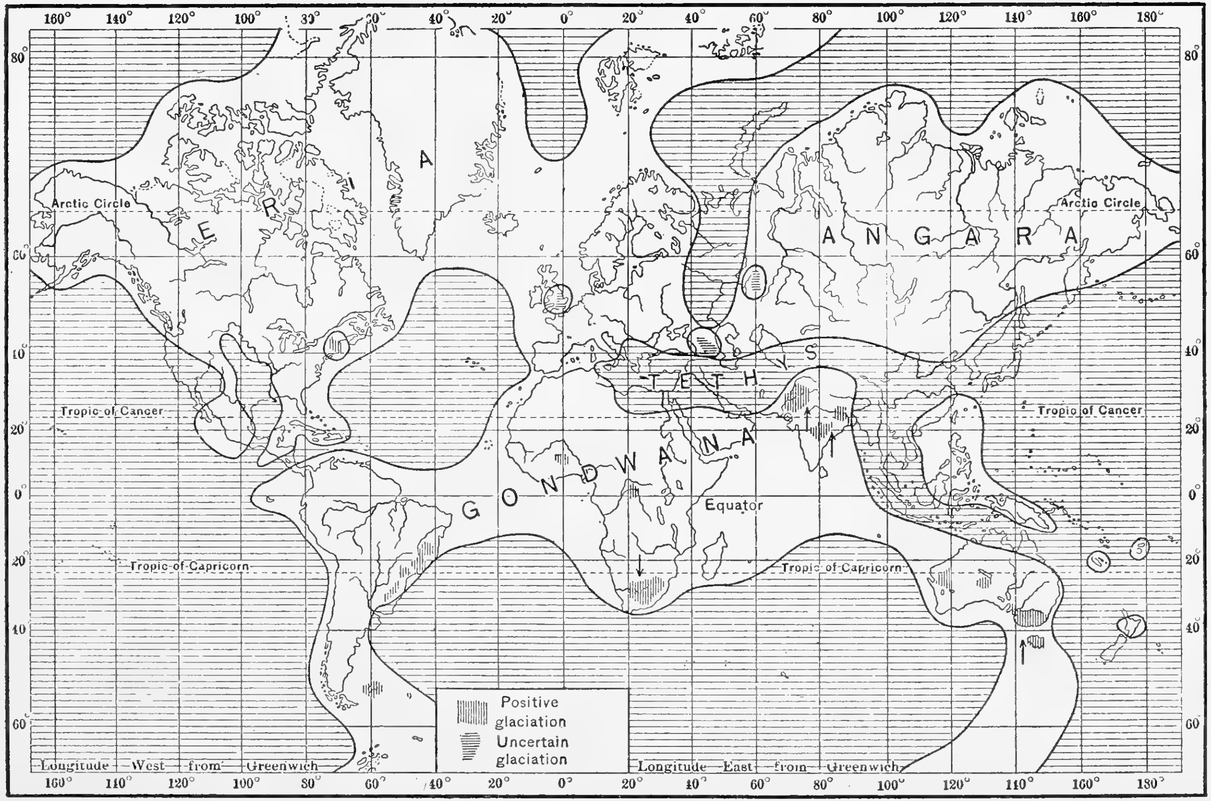

FIGURE 1.—*Paleogeography (and glaciated Areas) of early Permian Time*

Note the transverse shape and the connected condition of the continents. Arrows indicate the direction of glacier flow. From Pirsson and Schuchert's "Text-book of Geology."

are found only on the margin of the continents or on continental islands, and all of them do not total more than 1 per cent of the earth's surface. Even though the theory of the permanency of continents and oceanic basins is now of wide acceptance, it does not follow that the continents and oceans have practically retained their present outlines since the beginning of the Cambrian. On the contrary, it is held by many geologists—and more so in Europe than in America—that the continents have changed much in form and in area. My studies have convinced me that during the Paleozoic the continents were not only larger in area, but more especially that they were not then, as they are now, drawn out longitudinally. Originally there were two immense transverse or latitudinal continents (see figure 1). In the north lay Eria, the great holarctic land, at times uniting the Euro-Asiatic mass broadly with Iceland, Greenland, and North America; in the equatorial region lay Gondwana, extending from western South America across the Atlantic Ocean to unite with Africa, and broadly across the Indian Ocean to embrace peninsular India. Between these transverse lands lay the greater mediterranean, known as Tethys, uniting in the west sparingly with Poseidon (now the North Atlantic) and in the east broadly with the Pacific, the Father of Oceans. Gondwana was broken through in late Mesozoic time by Poseidon and Nereis, which together made the Atlantic, while Eria began to be fractured in the Cretaceous, though Europe, Greenland, and North America appear not to have been completely sundered until Miocene time. We therefore have here the phenomenon of oceanic realms enlarging at the expense of the continents. From this and the further evidence of volcanic activity throughout the geologic ages, it follows that the amount of water on the surface of the earth is greater now than it ever was, because enlarging basins hold increased volumes of water. The water of the enlarging hydrosphere is constantly supplied by the volcanoes and thermal springs, but what the percentage of increase has been since the Cambrian is unknown, though it has been placed as high as 25 per cent.

DISTURBANCES AND REVOLUTIONS

The continents periodically undergo elevation and mountain folding, and these times of crustal unrest all occur when the lands are the least flooded. This periodic readjustment in the earth-shell of North America is recorded by at least fourteen times of mountain-making. Eight of these are of lesser import, and may be spoken of as "disturbances" to distinguish them from the major movements that have long been referred to as "revolutions," of which there are six now named. The latter are also the "critical periods" in the history of the earth when mountains are

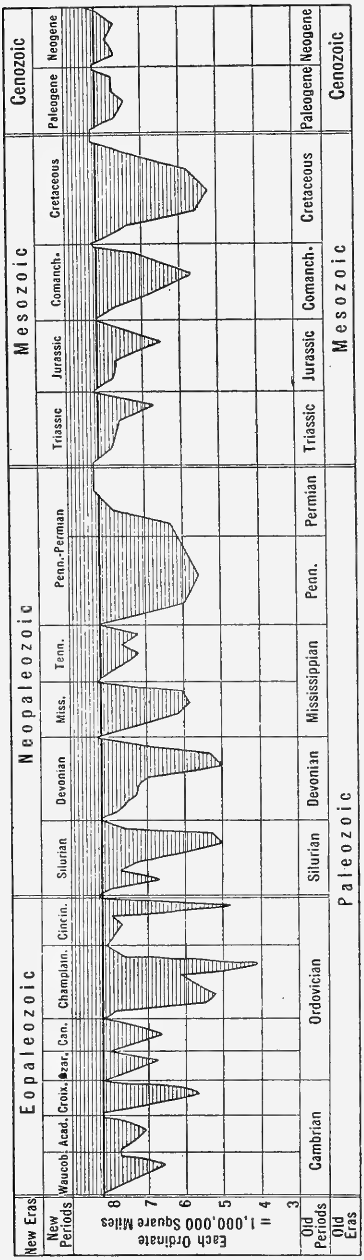

FIGURE 2.—*Diagram showing the Time and Extent of the known Floods that have inundated North America since the close of the Proterozoic Era*

made in most or all of the continents. The only established periods that in North America are not yet known to have been closed by marked crustal unrest are the Cambrian, Pennsylvanian, and Paleogene. If, however, the newer geologic chronology, which recognizes eighteen post-Proterozoic periods, is to prevail, then there are five additional times when North America is not yet known to have made mountains (Acadian, Croixian, Ozarkian, Champlainian, and Waverlian). I have no doubt that these additional disturbances will be found, but it is not essential to the newer classification that the deformation should have occurred in North America.

It is also now fairly well established that the hydrosphere has moved over the North American continent at least twelve times and in extent up to one-half of its area (4,000,000 square miles). There are, however, thirteen established periods, and the only Euro-Asiatic flood failing of record in our continent is that of Permian time (see figure 2). On the other hand, the new geologic chronology recognizes five additional times of flooding, and only one of these is as yet known to be closed by a disturbance (Lower Cambrian or Waucobian). In most cases, therefore, the periods of either the old or the new chronology are separated from one another by disturbances that, as a rule, are marked by conformable contacts. It is because of this want of marked unconformity between the

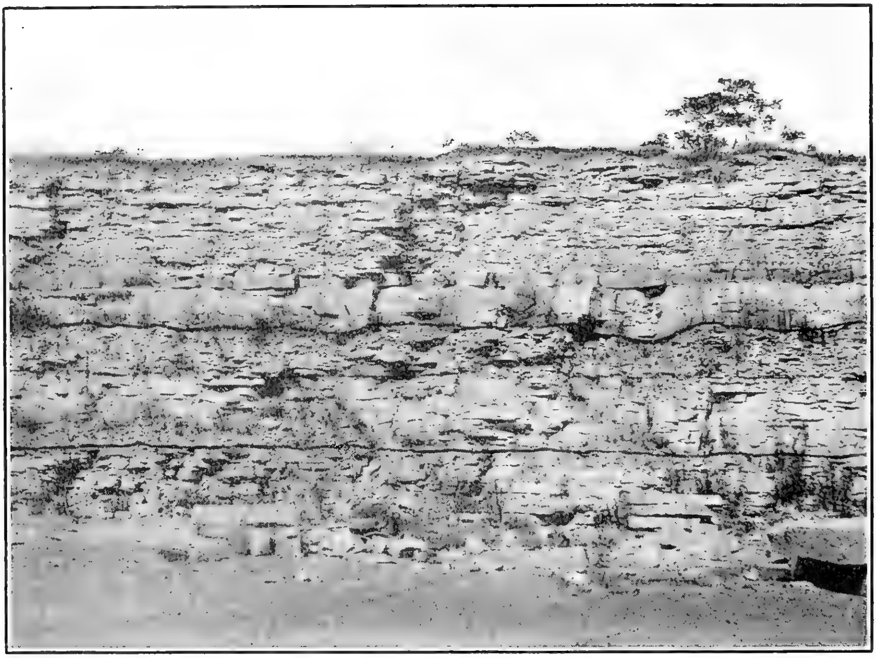

FIGURE 1.—DEVONIAN-SILURIAN DISCONFORMITY, BUFFALO, NEW YORK

Middle Devonian (Onondaga) limestone rests on the Silurian (Manlius); below is shown another break (Manlius-Bertie)

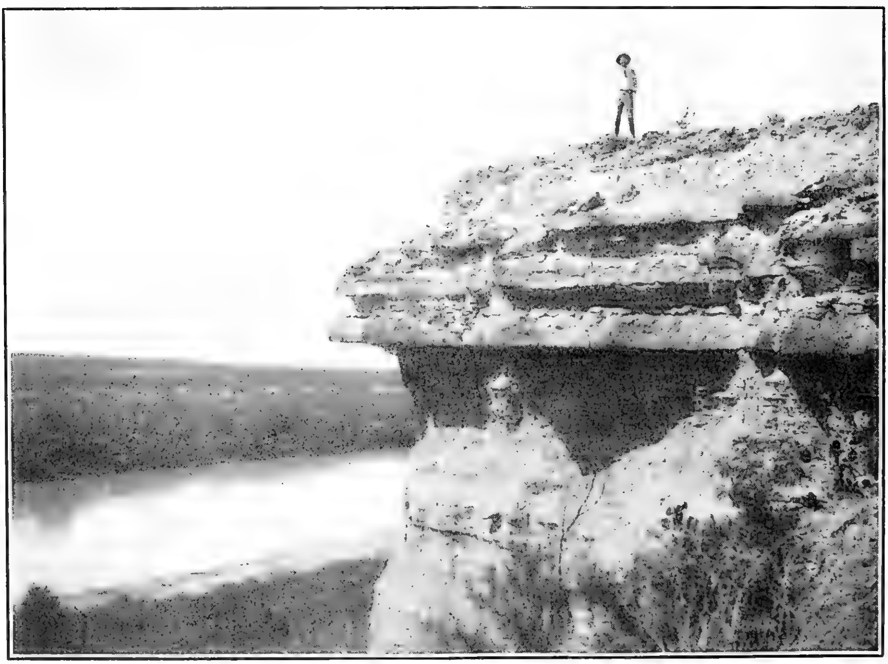

FIGURE 2.—PROJECTING LEDGES OF EOCENE (MIDWAY) LIMESTONE DISCONFORMABLE ON CRETACEOUS SHALE (ESCONDIDO), WHITE BLUFF, RIO GRANDE, TEXAS

Photograph by L. W. Stephenson, U. S. Geological Survey

ILLUSTRATIONS OF DISCONFORMITIES

new periods of Ulrich and Schuchert that the average stratigrapher is chary in accepting them (see figure 2).

BREAKS

The breaks in the geologic record are known to be many, and yet few stratigraphers appreciate their great number. The easily seen, marked unconformities, as, for instance, the one between the Cambrian and the Archeozoic in the Grand Canyon of Arizona, are of course accepted at full face value; but the many more apparently conformable and yet broken contacts, the disconformities, are generally overlooked, or when seen are generally undervalued (see plate 19, figures 1 and 2). It is probable that as much time is represented by the breaks as by the entire sedimentary record. This statement may appear to many as overdrawn, and yet the age of the earth estimated from geologic data is greatly at variance with the results attained by physicists on the basis of radium emanations. The differences are about as one is to eight, or even ten, and as the physicists have more reliable data on which to base their calculations, it follows that stratigraphers must either considerably elongate the geologic time-table or show that the rate of sedimentation varies greatly during the opening and closing epochs of the period when compared with the peneplained middle epoch. To emphasize the importance of breaks and their very unequal duration, it is sufficient to recall to mind the vastly long record that is absent on the Canadian Shield, where the Pleistocene drift generally reposes on the Laurentian granites of Archeozoic or Proterozoic time, or the case of the horizontal Pleistocene loess that rests conformably on Silurian limestone at Grafton, Illinois. The latter is a disconformable contact, and yet the record that is absent is equal to about one-half of the entire stratigraphic chronology.

In regard to the breaks, the statement can be made that there are at least ten disconformities for every known angular unconformity, and in the Ohio and Mississippi valleys, where the Paleozoic strata are nearly everywhere practically horizontal, there may be a hundred disconformities, and yet hardly anywhere is there to be seen a marked unconformity.

Methods underlying a determined Chronology

GENERAL DISCUSSION OF METHODS

The methods now in use in determining the stratigraphic sequence and in correlating the formations from place to place are of four categories. These in the order of immediate use are (1) the sedimentary method, (2) the paleontologic method, (3) the paleogeographic method, and (4)

the diastrophic method. It will be seen from this arrangement that diastrophism as an aid in stratigraphic correlation is the last method to be used; but the time will come when it will be of primary importance, because it is the periodic rhythm of changes deep within the earth's mass that brings about the elevation of mountains and the lowering and raising of the oceanic strand-lines. Let us now consider these four methods in the order given, since the sequence leads to ever more complicated methods of research.

THE SEDIMENTARY METHOD

Stratigraphy began in the discerning of the fact that superposed beds and formations in a continuous sequence must have the older beds below and the younger ones at the top. Therefore superposition of formations imposes on the fossils a definite stratigraphic value and further indicates the trend evolution has taken among the organisms. The nature of the sediments taken by themselves can not, however, be used safely in correlating widely separated localities having like formations, but may be of considerable value in local work when the exposures are not far apart. At all times the waters are depositing muds, sands, and limestones, and as their sequence is variable in closely adjacent places, it follows that the physical characteristics of the strata have the least value in correlation. Limestones in heavy beds, however, have as single units the greatest value, while sandstones and mudstones are the least usable in correlation. Even though limestones are apt to be of wide distribution, these organic deposits make up only 5 per cent of the water-laid strata, and it therefore follows that in actual practice they are of rare occurrence. On the other hand, 80 per cent of the sedimentaries consist of mudstones, and as these have the fewest fossils they are only of occasional value in correlation. An identical succession of differing clastic deposits is, however, far more reliable in correlation than the single units.

Passage beds, or transitions from one kind of sediment to another, are usually indicative of continuous deposition, and even a sharp contact between differing strata may not be indicative of a break or disconformity. On the other hand, a gradual transition does not preclude the possibility of a break being present. Breaks occur less often in passing from a sandstone to a shale, from a shale to a limestone, or from a limestone into a shale, and most often between a limestone and a succeeding sandstone. Marine conglomerates are generally the initial strata of a transgressing marine deposit, and are therefore of great value in directing attention to the presence of a break.

Sediments are of much service, however, in determining the ancient shorelines. For this purpose the marine conglomerates of rolled and

foreign pebbles are of greatest aid, and next after them the lateral transitions from marine into brackish and fresh water deposits. Cleanly washed quartz sandstones are usually good indicators of shallow seas and of nearness of land, but not necessarily of actual shore conditions. On the other hand, it is probably true that in the great majority of marine formations the shore and shallowest water deposits have been eroded back after each emergence, and for distances commonly up to 30 miles. In the Devonian of the Appalachian delta the shore deposits are now absent over an area of from 50 to 75 miles in width, and in the Cretaceous of New York and Massachusetts they are gone in a strip of land that is between 75 and 90 miles wide (Barrell).

THE PALEONTOLOGIC METHOD

The primary basis in correlating strata and arranging them in a chronologic sequence is the fossils that were entombed at the time the rocks were formed. Their succession, and therefore their stratigraphic value, have been determined from the superposition of the strata. With the aid of fossils we are also enabled to trace a formation from place to place, and thus to work out considerable of the geography of the time as well, and, finally, from a succession of formations, the times of diastrophic movements. On this occasion it is not my privilege to dwell on the paleontologic method, and I will take this opportunity to present only a few points that bear more especially on the making of paleogeographic maps.

A little insight into living faunas shows that their combination varies from place to place, and that while a few species are limited to a very restricted geographic range, the greater number have a more or less wide distribution. Among the marine invertebrates many of the sessile and semi-sessile forms are localized in a definite sedimentary facies; others are not so circumscribed, while the free species have a tendency to spread extensively. The degree of radiation is, however, very variable with each species, but in general the tendency is toward wide distribution.

Regarding the dispersal of living marine mollusks, Dall has presented very valuable data that have a direct bearing on the fossil faunas. He states that the Peruvian warm-water province extending from Guayaquil, Ecuador, to southern Chile has over 800 species of bottom-dwelling mollusks. In a straight line this province has a shoreline that is over 2,000 miles long, and yet more than 55 per cent of the species have a greater range, extending into the adjacent areas, while 40 per cent are restricted to the region. We may therefore say that about 60 per cent of living marine bottom-dwelling invertebrates have a range of between 2,000 and

3,000 miles, while at least 5 per cent have a coastal distribution greater than 5,000 miles. Smith also points out that many of the species and nearly all of the genera of the Upper Trias are common to California and the Alps, regions that are 6,000 miles apart in a straight line and 12,000 miles by the route of faunal migration.

It is this wide range of most of the marine invertebrates and the additional fact that all organisms, living and extinct, are changing, some very slowly and others faster, that enable paleontologists to work out not only their genealogies, but also the times of their geologic origin, duration, and vanishing. The evolution is in the main progressive in the introduction of new characters; a small per cent of the species are almost stationary in their make-up; more are regressive in the losing of inherited parts; and yet, in all this change, *no species is repeated in time.* These facts indicate that fossils can be depended on in the correlation of formations, and that the greater part of the faunas will radiate as far as the marine overlaps can spread. While it takes time for the sea to transgress the land, to the stratigrapher the faunas appear simultaneously in widely separated places on the same continent. As an example may be cited the fauna of the Galena and equivalent formations of the Middle Ordovician, which are common to Illinois, Iowa, Minnesota, and Arctic America. A later and easily recognized Ordovician fauna, that of the Richmondian, is known from Texas to Alaska and from Nevada to Maritime Canada. Again, the Upper Devonian Lime Creek fauna occurs in New York, Iowa, Arizona, and California, and parts of it are widely distributed in the Euro-Asiatic region. Smith has pointed out similar wide occurrences for the Triassic and Jurassic faunas of the Pacific States, and that the Triassic assemblage of Bosnia is duplicated in Nevada; therefore even intercontinental correlations can be made through the fossils, though here the difficulties are greater than for intracontinental time determinations.

THE PALEOGEOGRAPHIC METHOD

Paleogeography treats of the ever-changing geography of geologic time. It seeks not only to map the configurations of lands and seas and their relationship to one another, but to determine as well the topography, something of the structure and volcanic activity of the lands, the depths and circulation of the marine waters overflowing the lands, and the physical and chemical actions of the varying climates on the sediments. The constantly changing physical environment reacts on the organic world and causes it to alter variously in its parts; and as in one place or another sediments and organisms have been at all times adding themselves to the stratigraphic sequence, it follows that the interpretation of

this record will lead not only to a determined paleogeography, but also to a determined chronogenesis and phylogenesis.

The first guidance in the making of paleogeographic maps is found in the widely accepted postulate that the great ocean basins and the continents are to all intents and purposes permanent features of the earth's surface. However, even though the great continents have always been where they now are, their size and shape have not always been constant; some have been enlarged and others have been decreased and added in part to the oceanic areas.

Another essential in the making of these maps is the determining of the ancient coastlines and the sources of the sediments. Along the Pacific border it is natural to assume that we must be dealing in the main with epicontinental or shelf seas—in other words, with marginal overlaps of the Pacific Ocean—and that therefore the shorelines must lie to the east of the overlapping oceans. It is undoubtedly true that the most easterly shoreline of Pacific waters washed Cascadia,[2] but it does not follow that it was the strand of the open ocean; nor does it follow that Cascadia must have stood on the edge of the continent, for a study of the position of geosynclines leads to the opinion that this ancient land in Mesozoic time faced a narrow, but long and subsiding, trough that was bounded on the west by a marginal strip of probably long islands. The postulated paleogeographic condition along the west coast of North America during the Mesozoic was probably similar to the geography of the present peninsula of Lower California and the Gulf of California. Better examples are seen off the coasts of eastern Asia. Here the Sea of Japan, a greatly overdeepened geosyncline, is bounded on the east by the Sakhalin and Japanese drowned mountain chains, which together have a length of more than 2,000 miles, while the China Sea is bounded by Formosa and the Philippines, with a length of nearly 1,500 miles. On the other hand, the coarse character of the Mesozoic deposits, and especially the great thicknesses of the formations, combined with much volcanic material that is spread all along the Pacific border of North America, are in harmony with the theory that these sediments were laid down in a geosyncline, often having high lands bounding the trough on either side. We are further guided to the shorelines by the increasing coarseness and thickening of the formations, and more particularly by the transition of faunas from marine to brackish and fresh water types.

Having ascertained the significant guide fossils of a fauna and their stratigraphic range in the sequence, the next point of value is the deciphering of the geographic distribution of the formation containing the

[2] Bull. Geol. Soc. Am., vol. 20, 1910, pl. 49.

assemblage, or, in other words, the distribution of the sedimentary and faunal episode. Primary reliance is, of course, placed on the radiation of the fauna mapped, while the shorelines are determined from the nature of the deposits and the strike of the geosynclines.

Of considerable value in deciphering the probable extent of the transgressions whose traces are subsequently covered by other deposits is the geographic pattern of earlier and later invasions—that is, the situation of the positive and subpositive continental elements which remain fairly constant. An analysis of the American Paleozoic formations shows that they occur in greatest number and best development in the periodically sinking subpositive or geosynclinal areas, and less continuously in the neutral regions, and that these shallow seas are situated between rising positive regions where there is renewal of previous records and the furnishing of sediments. Along the Pacific border of the United States deposition may have all been restricted to the geosynclines, but in Canada and Alaska, previous to the Sierra Nevada uplift, there were, in addition, wide neutral areas with short sedimentary cycles.

All pioneer work in paleogeography must be very imperfect, and the attempts for the Pacific border will long remain the least satisfactory, because so little is as yet known of the geology of this difficult and not easily accessible portion of North America. My maps probably err most in that the marine transgressions depicted are too small in area, but it will be easy to enlarge them when the evidence is at hand. On the other hand, I strongly urge others to portray the ancient geography of single formations, because synthetic maps that embrace several or all the formations of a system can not lead to definite results. This is because too much time is embraced and seas are united that are inconstant, periodic in appearance, and more or less oscillatory in nature.

THE DIASTROPHIC METHOD

Under the term *diastrophism* are included all the movements within the earth's mass and reflected on the surface, remolding the topography of the lands and changing the shape, contour, and size of the oceanic hollows. It is this periodic elevation of the lands and the removal through erosion of the protuberant parts that cause the oceanic strandlines to shift back and forth over the continents, resulting in continental submergences and emergences, a diastrophic action that underlies a natural classification of the successive geologic events.

A shifting of the oceanic strand-line is indicated (1) by unexpected changes in the superposed faunas, (2) by the sudden appearance of unrelated species and genera, (3) by the obvious breaks in the stratigraphic

succession indicating sea withdrawals and erosion intervals, (4) by abrupt changes from marine to continental and from land to sea deposits or from limestones to sandstones, and (5) by overlapping or transgressing formations.

The larger crustal deformations are periodic in appearance and their visible areas of movements are now in one continent and now in another, and it is this periodicity that conditions paleogeography and quickens evolution. Each one of these active and decisive movements is of long duration, and their major work is confined to the marginal areas of the continent. At the same time the oceanic basins are made either deeper or larger, or both. This simultaneous movement of the oceanic bottoms and the continental margins is proved by the fact that the crustal deformations occur during the emergent and closing epochs of the periods. This is true not only for the continent deformed, but for other land masses as well that have not moved at all, for the strand-lines of the latter have also been lowered in consequence of the oceanic enlargement.

The long-enduring middle portion of the periods is marked by relative crustal stability, peneplanation of the continents, and maximum sea invasion, brought about in the main through the unloading of the continental protuberances into the oceanic basins. On the other hand, the first epoch of each period exhibits much crustal warping and marked erosion. The lands then warp more or less along predetermined lines, due to compensating deep internal adjustments following the major movement and to the reestablishment of the isostatic balance that has been altered by the deformation, by the sea invasion, and by the unloading of protuberant land areas into the loading seas. During the closing epoch of the periods there is a renewal of crustal unrest, seen in the vanishing of the inland seas, and finally ending in another marked crustal deformation and in more or less complete withdrawal of the oceanic overlaps.

There is a certain amount of rhythm in these periodic changes in the face of the earth, and it is this meter that permits of grouping the formations into the systems. Each long-enduring submergence with the following emergence is seemingly the natural basis for the delimiting of the periods. Among these periodic movements some are far more intense and of greater geographic extent than others, and at such times mountain ranges are thrown up in most of the continents. These are the diastrophic grand cycles, the critical periods or revolutions in the history of the earth, and they bind, as it were, the periods or disturbances into the eras.

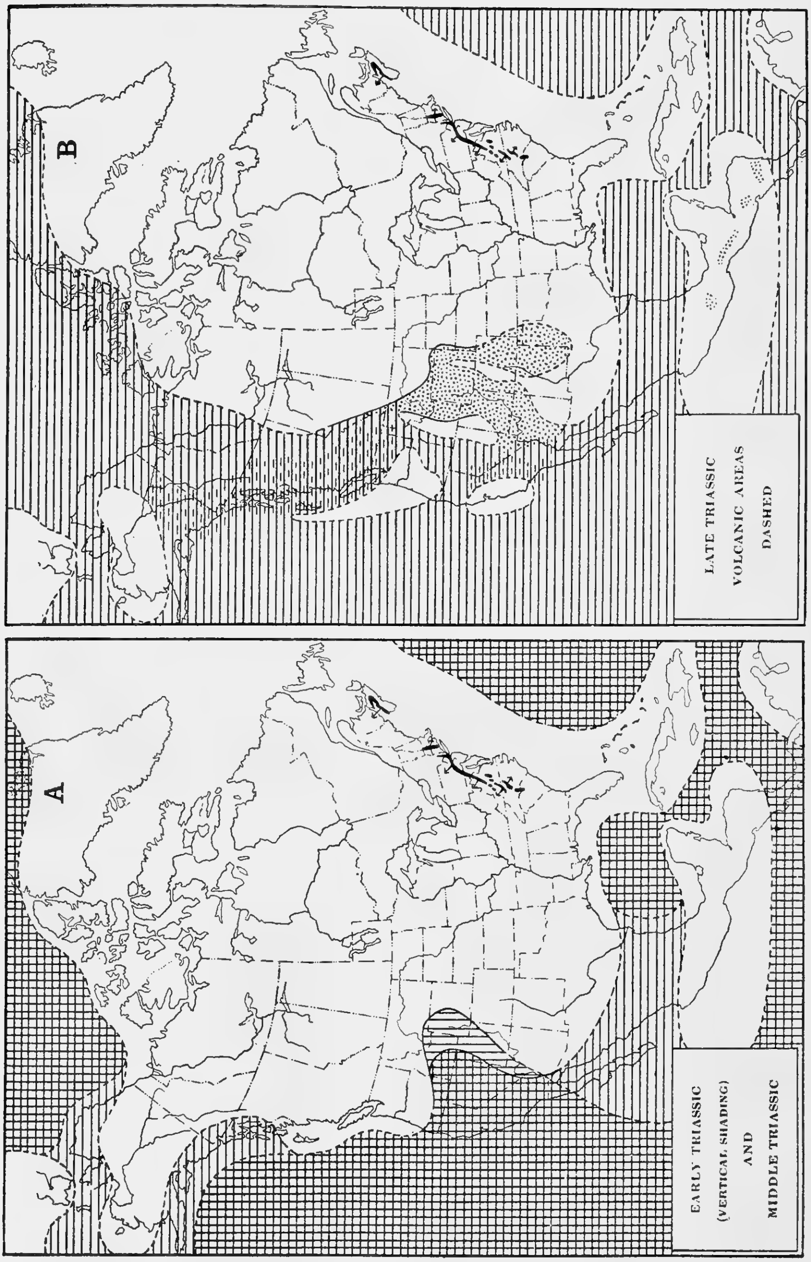

FIGURE 3.—*Triassic Paleogeography*

Eastern continental strata in black; western, dotted; volcanic areas indicated by dashed lines. After Schuchert, "Text-book of Geology"

Paleogeography of western North America during the Mesozoic

INTRODUCTORY

Let us now apply the methods just stated to the paleogeography of the west coast of North America during Mesozoic time.

TRIASSIC TIME

(See Figure 3)

Our knowledge of the west coast Triassic is good only for the States of California, Nevada, and Oregon, and is due mainly to the work of Prof. J. Perrin Smith. He states that the development of the Triassic of these States is unusually complete, and in thickness compares favorably with that of any other region of marine sedimentation. The deposits are usually calcareous and fairly thick (about 4,000 feet), and increase in volume with the progress of time, facts which are in keeping with the view that, as no mountain ranges were developed along the Pacific border in Permian time, there was no high land present to furnish the adjacent seas with much sand and mud.

Along the Pacific border of British Columbia, from Vancouver north to the Queen Charlotte Islands, the Triassic, and chiefly the early Upper Triassic, is of great thickness, attaining, according to Dawson, to 13,000 feet, of which more than nine-tenths is of submarine volcanic origin. With these materials are interbedded zones of marine sediments, argillites, and quartzites that are thin or even absent to the east. The volcanoes of Middle and Upper Triassic time extended from southern California into Alaska, and near Mount Saint Elias there are about 4,000 feet of basalts, followed by the same thickness of Upper Triassic limestone (Chitistone) and 2,500 feet of dark shales.

The Pacific overlap had its widest distribution in the early Upper Triassic, for its deposits occur at various points along the western border of North America and widely over Alaska and Arctic America. In the United States throughout the Rocky Mountain area the Upper Triassic is developed as a continental series of sandy red or variegated shales and cross-bedded sandstones.

In Alaska along the Pacific border, from at least Mount Saint Elias to the middle of the Aleutian peninsula, a distance of fully 800 miles, the Triassic and older formations were thrown into a folded series of mountains and injected by igneous rocks at the close of the Triassic. It seems very probable that the uplift extended across the peninsula of Alaska far southward into British Columbia. Finally, a marked break in sedimentation separates the Jurassic of California from the Triassic—a condition

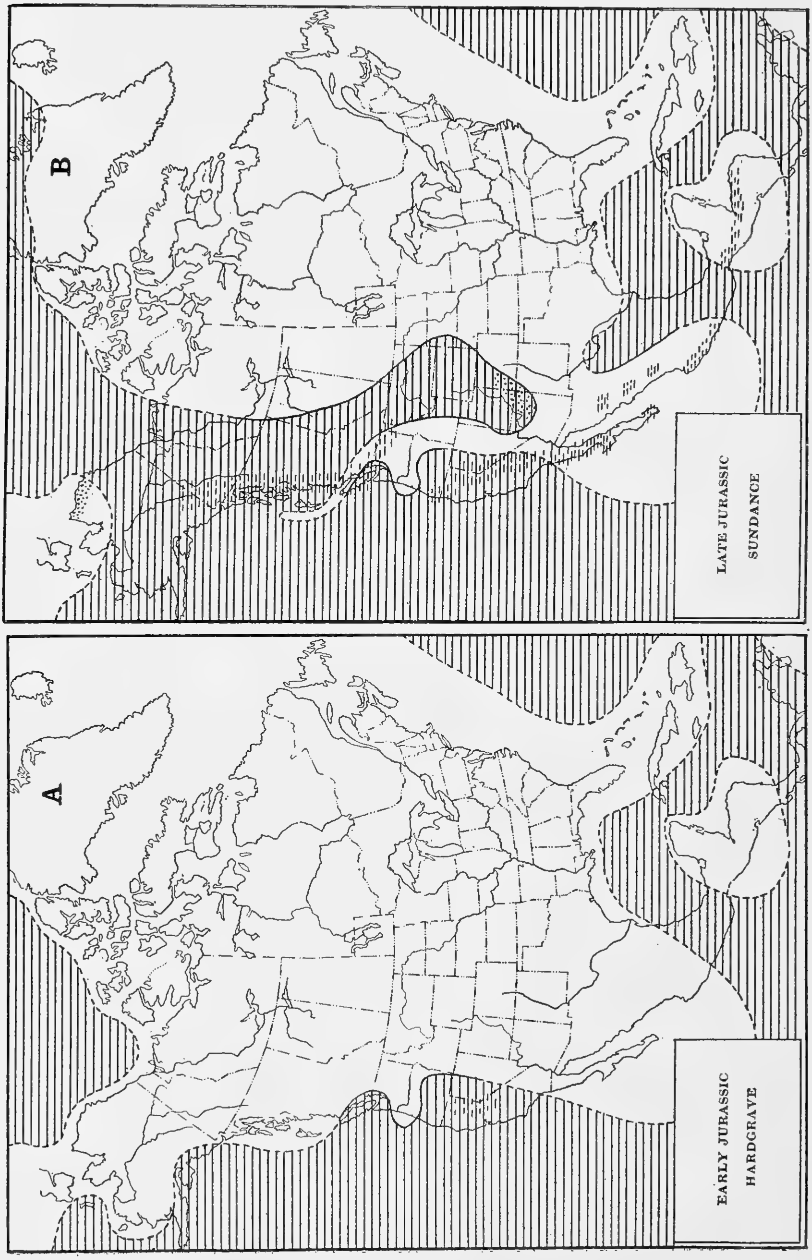

FIGURE 4.—*Jurassic Paleogeography*

Areas of bathyliths and elevation indicated by dashed lines. After Schuchert, "Text-book of Geology"

also common to the entire Pacific Coast region, for nowhere are there, according to Smith, any marine Rhætic strata. To emphasize this marked diastrophism, the period of orogenic mountain-making has recently been named the *Chitistone Disturbance,* after the thick limestone of the same name, so well developed in southeastern Alaska.

In this connection it is well to direct attention to the fact that the Triassic of eastern North America was also deformed at the close of this period. The Palisade Mountains of Dana, a series of faulted or block mountains, were in existence then from Nova Scotia to South Carolina, a distance of 1,000 miles. This disturbance is known as the *Palisade Disturbance.*

JURASSIC TIME

(See Figure 4)

It was stated that the Triassic period closed with crustal warping and deformation all along the entire Pacific border of North America, and that mountain-making on a considerable scale took place at least throughout Alaska. In consequence the sea appears to have been removed everywhere from the continent.

The Pacific Ocean again began to invade North America early in Jurassic time, sparingly in the Aleutian peninsula, the Cook Inlet country of Alaska, and across Vancouver Island. Of Middle Jurassic events little is as yet well known, other than that the Lower Jurassic of Alaska, with a thickness of 1,000 to 4,000 feet, continues, according to Stanton and Martin, unbroken unto the Middle (1,500 to 2,000 feet) and Upper Jurassic (5,000 feet). The total thickness of the marine Jurassic in Alaska exceeds 10,000 feet, and consists essentially of coarse deposits, such as tuffs, conglomerates, sandstones, and shales, with andesitic lava flows near the top of the series. This is largely the material from the Chitistone Mountains, formed at the close of the Triassic.

In the Californian Sea, an independent faunal province of Oregon, California, and Nevada, sedimentation appears to have been continuous throughout Jurassic time, but the detail of the formations is well known only locally. The strata of the Gold Belt series—the Mariposa and Auriferous formations—of northern California and Oregon are essentially sandstones and shales, with very little of limestone and about 500 feet of tuffaceous conglomerates. In places the thickness is 2,000 feet, rising to over 6,000 feet elsewhere in California, and if the Lower Knoxville strata of 10,000 feet thickness, with their Jurassic flora, belong here, the maximum thickness will rise considerably above the last-mentioned figure. In the Humboldt Range of Nevada there are from 1,500 to 2,000 feet of

basal Jurassic limestone, followed above by 4,000 feet of slates. Evidently the Upper Jurassic material was derived from a high land, and in places these formations are seen to rest unconformably on the Triassic.

Toward the close of the Middle Jurassic the northern Pacific, with a cool-water fauna, began to spread widely over Alaska and British Columbia, and, as the Logan Sea, continued into the States of Montana, Idaho, Wyoming, Colorado, and Utah. In the Great Plains region the deposits of the Logan Sea have an average thickness varying between 200 and 400 feet, but increasing to the west to upward of 1,000 feet and in southwestern Wyoming to 3,500 feet. The cross-bedded sandstones, the changeable sediments, and the general prevalence of oysters indicate that the sea was a shallow one, and, further, that it flowed over a warped land eroded to a low relief.

Volcanic activity began again locally along the Pacific border of North America early in the Jurassic and continued throughout the period, becoming more marked toward its close than at any time during the Triassic. The eruptions were in part submarine.

Toward the close of the Jurassic the Sierra Nevadas, the Coast Range of California, and the Humboldt Range of Nevada were elevated; also the Cascade and Klamath Mountains farther north. The making of the Sierra Nevada Mountains at this time was pointed out by Whitney in 1864 and further described by Dana. The marked significance of this deformation has been emphasized more recently by Lawson, who regards it as having the importance of a revolution, and Smith has given it the name Cordilleran Revolution. Last year Blackwelder called it the Nevadian movement, but it seems better to retain the older implied term of Sierra Nevada, just as we speak of the Appalachian and Laramide revolutions. That the Sierra Nevada movement was of wide extent and that it was of greater importance than the average disturbances closing the periods is admitted, for it is probable that mountains were made extending from Mexico into southern Alaska, and yet it had not the importance of a revolution, when mountains were made in nearly all of the continents. For these reasons I prefer to call it the *Sierra Nevada Disturbance.*

The Sierra Nevada deformation also shut out the Arctic-Pacific intercommunication and prevented further wide overlaps of the Pacific Ocean over Canada and the United States. With the rising of these mountains also began the formation of two new troughs or geosynclines. The smaller one, which was clearly developed in latest Jurassic time, Le Conte has named the Shastan Sea, and of this the present Great Valley of California is the structural remnant. The other, of far greater extent, I have recently named the *Coloradoan geosyncline,* but it was not in full development until Cretaceous time.

While the Pacific border of North America was being folded in late Jurassic time, the earth-shell was also invaded by deep-seated igneous rocks (granodiorite) on a large scale. Magmas in great volume were intruded, forming the great chain of bathyliths now exposed by erosion from Lower California to the Alaskan peninsula. In comparison with this intrusion, Lindgren states that all post-Proterozoic igneous phenomena fade into insignificance. The bathylith of the Sierra Nevada is 400 miles long, with a maximum width of 80 miles. On the International Boundary there are twelve bathyliths with a width of 350 miles. Farther north appears the Coast Range bathylith, according to Le Roy probably the greatest single intrusive mass known, which extends unbroken for 1,100 miles into the southern Yukon country, with a width of from 30 to 120 miles.

SHASTAN TIME

(See Figure 5)

Into the newly made and subsiding trough of the Californian Sea the Pacific Ocean spread, while in British Columbia and Alaska the same waters gradually encroached more and more widely either as a shelf sea or, more probably, another trough—the Columbian trough. The sediments poured into these seas were coarse-grained and were delivered to them by the rivers flowing out of the highlands apparently in the main to the eastward.

The deposits are essentially sandy shales with thin bands of sandstone, local conglomerates, and rarely thin limestones. The thickness in northern California appears to be between 9,000 and 10,000 feet, of which about one-third is of Knoxville time, while the remainder is of Horsetown time.

The Shastan series of Gabb and Whitney (1869) is also known in northern Washington and along the Canadian and Alaskan coasts. The deposits are dominantly sandstones with sandy shales, and in most places include from a few hundred to 3,350 feet of lavas, tuffs, and ash beds. In the Queen Charlotte Islands, where these strata have coal beds, the depth is estimated at 9,500 feet, and elsewhere, although somewhat less, the thicknesses are rarely as low as 2,000 feet.

The sands and muds of the Shastan series in most places overlap unconformably the older and often metamorphosed formations. This unconformity is sometimes marked, as in the Klamath Mountains and the Coast Range, or is of the erosional type. However, there are also disconformable contacts. The faunas, as pointed out by Stanton, are of the Indo-Pacific realm and are remarkably distinct throughout from those

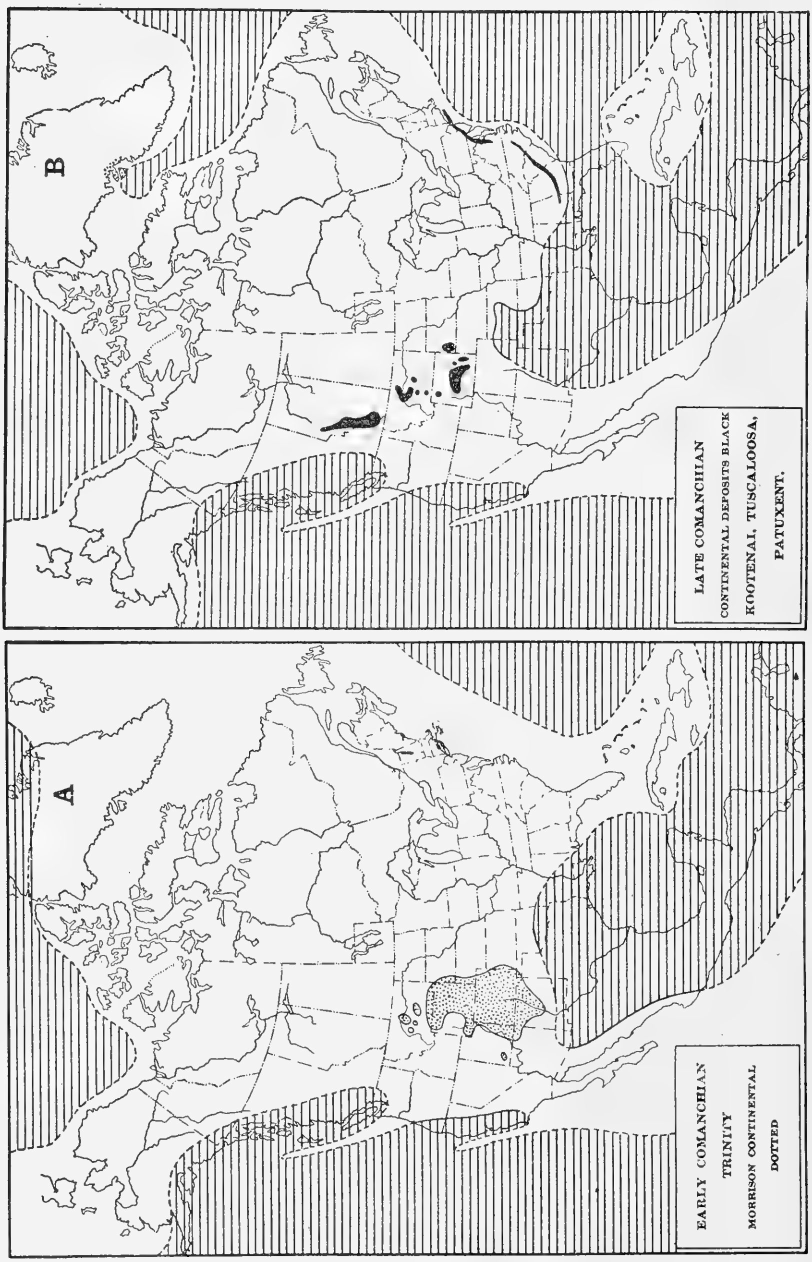

FIGURE 5.—*Comanchian Paleogeography*
After Schuchert, "Text-book of Geology"

of the Comanchian seas, which are of the Atlantic-Tethyian realm, a condition indicating that the two provinces were more or less, though not completely, separated from one another by a land barrier, the Mexican peninsula.

Along the Pacific coast from San Luis Obispo County, California, northward far into Oregon there is evidence of crustal movement during Shastan time. Anderson states that the Knoxville is everywhere in this

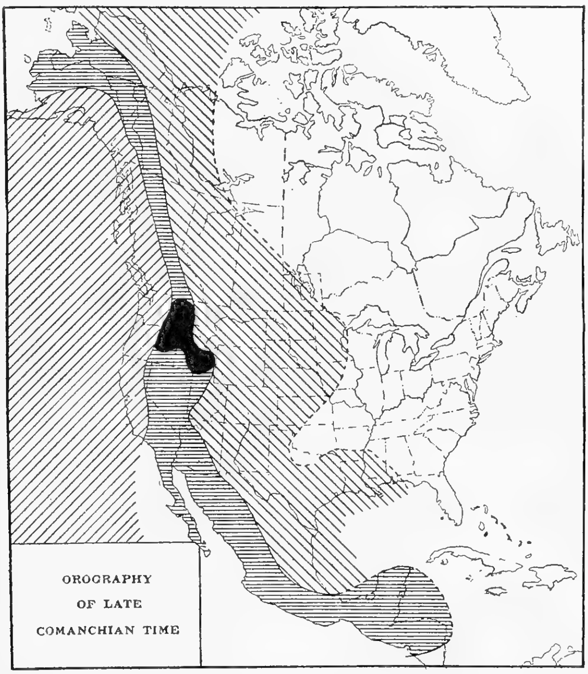

FIGURE 6.—*Map showing Regions of Elevation (horizontal Shading and solid Black), the Formation of the Coloradoan Geosyncline (right-hand oblique Lines), and the Pacific Overlap.*

Generalized from Ransome, "Problems of American Geology." The black area is that of the present Columbia River Plateau; the region of elevation to the north is known as the Northern Interior Plateaus, while that on the south is the Nevadan-Sonoran region.

area penetrated and disturbed by dikes and masses of serpentine and peridotites. Moreover, in the Coast Range of southern California, where these intruded rocks occur, the Horsetown strata are also absent, while the Chico of Cretaceous time unconformably overlies the older formations.

In western Utah, eastern Nevada, and throughout Idaho uplift was making itself felt as early as Middle Triassic time, forming the arch of the Columbia River Plateau, which persisted into late Jurassic time (the

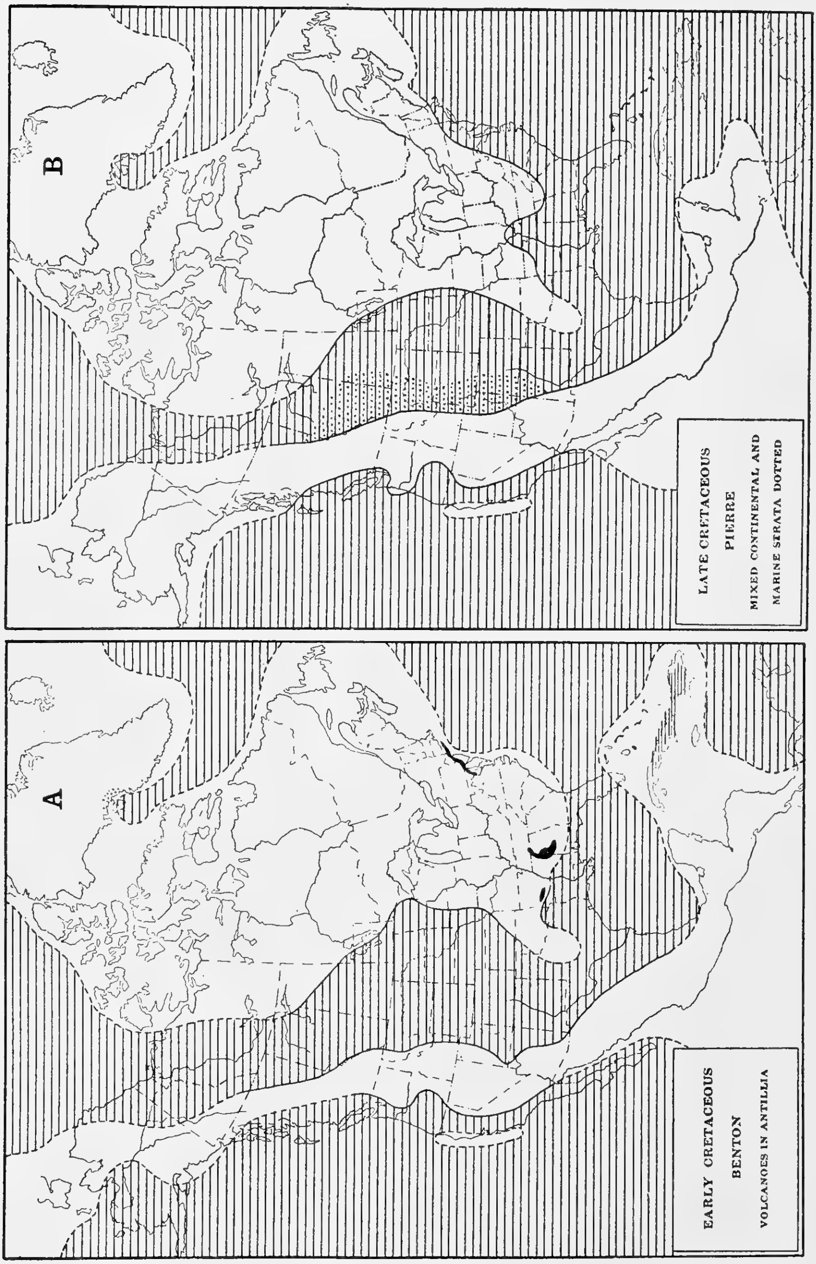

FIGURE 7.—*Cretaceous Paleogeography*
After Schuchert, "Text-book of Geology"

black area in figure 6). At the close of the Jurassic, however, the Sierra Nevada folds were thrown up to the southeast of this arch, and it was then incorporated into the area of the Sierra Nevada Disturbance. We have seen that this late Jurassic movement also forever shut out the former wide extension of the Pacific, not only from the area of the United States, but from most of western North America as well.

When we study the paleogeography of Cretaceous time, it soon becomes apparent that the conditions of oceanic spreading had been further altered toward the close of Shastan time, for subsequent to this period the Pacific overlaps were narrow (oblique lines to left in figure 6), and over what is now the site of the Rocky Mountains, and far to the east in both Canada and the United States, a new inland sea appeared—the Coloradoan Sea of Cretaceous time—extending from the Gulf of Mexico into the Arctic Ocean (oblique lines to right in figure 6). The barrier that kept these waters apart was the newly bowed-up land to the west of the present Rocky Mountains, the Cordilleran Intermontane Belt of Ransome, and this barrier continued to rise throughout all of Cretaceous and much of Tertiary time (horizontal lines in figure 6). We see here, therefore, the beginning of the process which made the Cordilleran Intermontane Belt of elevated plateaus, extending from Arctic Alaska all the way into Central America, and it is for this reason that the movement may be called the *Cordilleran Intermontane Disturbance.* Blackwelder has recently named it the Oregonian deformation, but this term is of altogether too local significance.

CRETACEOUS OR CHICO TIME

(See Figure 7)

The Chico series of sandstones and shales, with local conglomerates and coal beds, usually overlies the Shastan formations unconformably. These coarse deposits and thick formations are found all the way from the Lower Yukon, the Alaskan peninsula (1,000 feet thick), Queen Charlotte (11,000 feet) and Vancouver (5,000 feet) islands, middle and southern Oregon (4,000 feet), the Sacramento Valley (9,500 feet), and the Coast Range of California, to San Diego and the peninsula of Lower California. Stanton states that the Chico series begins somewhat earlier in time and continues longer than the Colorado series of the great Interior Sea, but does not embrace strata of youngest Cretaceous time. The Chico faunas are of the Indo-Pacific province and are markedly different from those of the Coloradoan and Mexican seas. The two provinces were separated from one another by the rising Rocky Mountain barrier.

The Cretaceous period and the Mesozoic era were closed by the Laramide Revolution. The area of folding and thrusting embraced the mountains of western North America, the Antillian region, and the Andes of South America—two grand mountain chains that extended from Cape Horn to Panama and from southern Mexico far into Alaska. Volcanic activity began late in Cretaceous time and continued into the Eocene, and the volcanoes extended from Mexico City and Arizona north far into Canada.

In conclusion, let me add that I have pointed out only the broader events and the general paleogeography. The more interesting detail and the actual ancient geography remain as the work of the rising generation of west coast geologists and paleontologists.

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VOL. 27, PP. 515-524 SEPTEMBER 1, 1916
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

METHODS OF CORRELATION BY FOSSIL VERTEBRATES[1]

BY W. D. MATTHEW

(Read before the Paleontological Society August 3, 1915)

CONTENTS

INTRODUCTION

It is a time-honored custom to begin a discussion of a subject by a brief sketch of its history, to outline what we used to believe about it, but have outgrown. My old teacher at Columbia, Professor Egleston, used to begin his lectures on metallurgy by explaining to us at great length the old practice, which even then was quite out of date, in order, as he said, that we should know what not to do. Most of us, I am afraid, rather begrudged the time so spent, as we wanted to get some grasp on present practice and probable future developments. Nevertheless there is more than a little advantage in knowing the history of any theory or practice, the trend of its development, the ideas that used to lie back of its methods; for it is almost always true that these discarded theories control our practice and methods to an extent often unsuspected. We are very apt to fail to apply our beliefs logically and to rest on rule-of-thumb methods, whose origin and sanctions lie in the accepted theories of former generations. The dead hand lies heavy on us and controls our procedure more than we think for.

Certainly this is true of correlation. If we turn back a century or so to the days of Cuvier, we find the doctrines of catastrophism in full sway. A succession of faunas, each created *de novo* after its predecessor had

[1] This paper was the second in the symposium, "General consideration of Paleontologic criteria used in determining time relations," read at the summer meeting of the Paleontological Society at the University of California, August 3, 1915.

Manuscript received by the Secretary of the Geological Society April 6, 1916.

been wiped out of existence by a universal revolution. Such was the testimony of the rocks as read in those days. Such was the belief in which geologic correlations were made. With this viewpoint correlation was a very simple and quite exact science. You were dealing with one distinct fauna or with another. Intermediates, intermixtures, survivals, were not thought possible. Each formation, each fauna, was clean cut, distinct, separate. A sample was sufficient to identify it. A very fragmentary record was amply sufficient to indicate which of the successive distinct fossil faunas you were dealing with. Each stratigraphic unit, each faunal unit, had its definite place in geologic time. Correlation was a rather simple matter and involved merely a sufficient knowledge of each fauna to recognize it when you saw a sample of it.

Under the influence of these views the succession and distribution of geologic formations and the sequence of faunas was worked out in detail in western Europe and more sketchily in the eastern United States; the foundations of our systems and nomenclature were laid. When the doctrines of evolution were first promulgated, the geologic record, interpreted and recorded in terms of the older theories, seemed to furnish the strongest and most direct argument against the new views. Today it is recognized as affording the most direct proof, the most unshakable evidence in their favor. Yet the facts stand substantially the same; we have reinterpreted their meaning, broadened the scope of our data, and realized the vast complexity of the life processes of which they furnish the historical record.

In practice, however, we are still controlled more than we realize by the empiric methods that grew up under the older viewpoint. In theory we believe in continuity; in practice we adopt correlations and map strata as though catastrophism were the rule, as though the gaps in the record were universal and correspondent throughout the world.

These preliminaries may serve as an excuse for the admission that theory and practice are not altogether in accord in vertebrate correlation work. The practice has been, and still is in large part, to use the ordinary current methods of stratigraphic geology, to draw up and compare lists of faunas as complete as possible, and to judge of the relations of the horizons by the degree of correspondence of these faunal lists. Yet the work of leading paleontologists in recent years, while it may retain this form, shows in its conclusions a clear recognition of the reservations and modifications necessary in applying such methods.

Fossil vertebrates have certain obvious advantages for correlation as compared with invertebrates and plants. They have other disadvantages equally manifest. These advantages and disadvantages involve certain

differences of method in making the best use of them. The differences are of degree rather than of kind.

Principles

The fundamental principle which underlies all faunal correlation is evolutionary change. Every species, every race, is changing more or less slowly, giving rise to new species, branching out into various forms or becoming extinct and succeeded by other races which have been similarly changing. These changes do not proceed uniformly over all parts of the world, but new types appear in one region, spread more or less widely over the earth's surface, and are in their turn succeeded by others. Primitive types may linger in remote and isolated regions long after they have been displaced elsewhere by more progressive stages. They may survive through the adoption of some special mode of life that withdraws them from competition with the more progressive species, or they may acquire some special mode of protection which enables them to survive. In none of these cases do they survive unaltered; always they are changed more or less in adaptation to their special habitat, but are less advanced than their more progressive contemporaries.

The rate of change varies widely in different races. The higher and more complex animals are more sensitive to external conditions; their changes in structure are far more rapid and obvious. This is especially true of the higher vertebrates.

The evolutionary changes are essentially an adaptation to a continually changing environment. The inherited characters of the race have been gradually assumed and impressed on it by the influence of the successive environments through which its ancestors have passed. The acquired characters are assumed in response to its adaptive needs. Similar adaptations imposed on two different races will result in the superposition of a superficial resemblance due to the identity of environment on a more fundamental difference due to different inheritance.

It is in these matters that the difficulties of correlation lie. We have to distinguish if we are to obtain true correlations between persistently primitive survivals and the similar but more ancient forms from which they are derived. We have to distinguish between resemblances in the faunas due to similar environment and those conditioned by similar age. The sure recognition of these distinctions depends on the completeness of our evidence. If the fossil remains of the animal enabled us to know its structure completely and in detail, it might be difficult, but would always be possible, to distinguish; but the fossil remains afford only incomplete and partial evidence. Internal structure affords better evidence

than external form, for it is more indicative of affinity and less of adaptation. Complex structure affords a better guide than simple, for it is more subject to change and the alteration more readily recognized. The more complete, the more complex, the more the internal structure is represented, the safer guide is the fossil as to the affinities and position of the animal whose existence it records.

Marine invertebrate faunas have generally been regarded as the standard basis of geologic correlation. For this there are excellent reasons. The marine succession is far more widespread and uniform than most terrestrial formations. Its invertebrate fossils are abundant, characteristic, wide-ranging; the evolution, migration, and succession of the faunas have been thoroughly studied, rest on a vast mass of evidence, and in most cases must be regarded as finally settled, at least in their broader outlines.

Fossil vertebrates, on the other hand, are comparatively rare, usually fragmentary, and owing to the scarcity of the evidence and the complex problems presented by their evolution and migration they may frequently be misinterpreted in correlation work.

There are nevertheless certain advantages in correlation by means of fossil vertebrates to offset these disadvantages.

In the first place, the skeleton of a vertebrate is an internal structure, highly complex in its construction as compared with the hard parts of most invertebrates. For this reason the affinities of a fossil vertebrate can be more exactly and more securely determined than most fossil invertebrates, provided that our specimens are sufficiently complete.

In the second place, the geologic range of species and genera of vertebrates is more restricted than that of most invertebrates and plants. They enable us, therefore, to make more precise correlations. This is especially true of Tertiary mammals, and in particular of certain groups of mammals of progressively specialized adaptation and wide geographic range.

It is in the correlation of land and fresh-water formations that vertebrates are chiefly useful. Fresh-water invertebrate faunas are comparatively limited in variety, and nearly all of them relatively simple in the structure of their hard parts and apparently very slow to change. Plant remains are similarly limited in their usefulness for correlation purposes, so that while invertebrates and plants are in general far more abundant and easy to find, the vertebrate faunas, if sufficiently complete, will afford more exact conclusions.

The great difficulty in using fossil vertebrates for correlation work is in the identification of fragmentary material. Most of our material is fragmentary, and its value varies widely according as it is more or less

characteristic and the identification for this and other reasons more or less exact and reliable. The old, and still usual, method of correlation is to compare lists of faunas and to judge by the number of common species how nearly the horizons correspond. It is not the best method, indeed; but it does yield results that agree fairly well with the more reliable results of comparisons of geologic range of each species. But the method is either misleading or perfectly worthless with fossil vertebrates; for most of the faunal list depends on identifications of fragmentary material; some may be, nevertheless, exact; most are essentially provisional. The evidence of one complete skull or skeleton may well outweigh that of the entire remaining list. And, on the other hand, a single very characteristic tooth may be of more value than much more complete and abundant material.

In correlating marine formations vertebrate fossils are of comparatively limited use, owing to their rarity. But some of them, especially the wide-ranging marine reptiles, when they can be found, are of high value in comparing distant regions, owing to their wide geographic range. But here, again, we must have adequate material if we desire precision in our results. In the correlation of the upper chalk of Europe and North America the Mosasaurs afford evidence of high value and precision, because they are completely known and have been carefully studied. Their evidence in correlation has not indeed been fully studied, but I can say with confidence that it is an important check, if no more, on the evidence of the invertebrates. I have less confidence in the accuracy of results obtainable from the more fragmentary Cretaceous Mosasaurs of New Zealand, Australia, and South America. If the complete skulls and skeletons of these southern genera were known and carefully studied, it would probably enable us to correlate the Cretaceous formations of the southern continents with more certainty than we can at present. But identifications at present current are probably in need of revision. They are not in accord with the invertebrate evidence and not positive enough to oppose to it.

Tertiary marine mammals would, if more numerous and better known, afford very valuable evidence. But until we know more of their evolution and geologic history I am indisposed to give much weight to them. Nor do I think that enough is known about Mesozoic mammals for their evidence to be of any serious importance in correlation of the Triassic, Jurassic, and Cretaceous horizons. The Mesozoic land Reptilia, on the other hand, are already of high value and will be of much greater weight in the near future in correlating terrestrial formations of this era.

It is chiefly in dealing with terrestrial Tertiary formations that the

vertebrate evidence is important. These formations are peculiarly difficult to correlate. Difference in facies due to different conditions of environment and deposition results in wide diversity of contemporary strata and faunas. This is also true of marine formations. But terrestrial faunas are much more provincial than marine, especially during and following epochs of submergence and isolation of the continental masses, where the marine faunas are most widespread and cosmopolitan. Direct correlation through identical species is possible only within limited regions, and in most instances, where there seems to be a correspondence of species, a rigorous investigation is necessary to find out how far this is merely due to hasty identification of fragmentary material and not valid for precise correlations.

The only methods practicable when dealing with fossil mammals of two widely separated regions are, first, the equivalence in stage of evolution of related or corresponding species; second, the first appearance of identical genera new to both regions; third, the extinction of identical genera or families common to both faunas, and, fourth, the degree of difference between the extinct and the modern faunas of the two regions compared. All of these methods are more or less untrustworthy unless they are combined with a knowledge of the evolutionary history and dispersal of each group of species or genera compared, which will in varying ways modify the interpretation of the data regarding its distribution.

Summary

Correlation difficulties are of two kinds—one practical, the other theoretical.

The practical difficulties are the scarcity or fragmentary character of the fossils, doubts as to their true stratigraphic position, as to the accuracy of identification.

The theoretical difficulties may be summed up as the distinction of homotaxis from true synchronism. The assumption that closely related equivalent or identical species appeared and became extinct at the same time in all parts of the world has long been recognized as theoretically untrue. Yet in practice we base our correlation work chiefly on this false assumption. It is true that the error is negligible in all broad correlation work. But in the more precise correlations which are now being worked out it is not negligible, and the discrepancies may in some cases be very considerable.

In dealing on the above principles with Tertiary mammal faunas the following conclusions must be emphasized:

1. Proportions of extinct to living species or genera afford no satisfactory comparison of age in two extinct faunas. The proportion of living genera of mammals recorded in any Tertiary formation depends a great deal on the families and orders that happen to be best represented, some being more conservative than others; on the region where it is found and the facies that it represents, most of the modern types appearing earlier in the Holarctic region and the open plains and uplands rather than forest and swamp environment and the more peripheral regions of the terrestrial world, where the older and more primitive stages are apt to persist; on the completeness of the specimens found and the conservatism of the describer, since fragmentary specimens of an extinct genus or species will often be indistinguishable from an existing one nearly related, and the standards of specific and generic distinction are far from uniform.

The Pleistocene fauna of South America, for instance, contains an extraordinary proportion of extinct species, genera, and even families, in comparison with that of North America and Europe. On this account it was very generally regarded as older, referred to the Pliocene. The Tertiary faunas of western Europe described by older writers from fragmentary material have been more largely referred to existing genera and species than a modern revision of the fauna with more complete material would admit. In consequence these faunas appear to be of more modern type than they really are.

2. The general equivalence in evolutionary stage of two faunas is likewise an unsafe guide. It may be fairly dependable, provided the faunas are equidistant from their principal center of dispersal. Otherwise it is very likely to be misleading. The modern fauna of central Africa has a great deal of resemblance to late Tertiary fauna of the Mediterranean basin. The Pleistocene fauna of Mexico has much in common with the Pliocene fauna of the United States. On the other hand, the successive Tertiary faunas of the United States and Europe, on opposite sides of the great Asiatic land-mass, correspond on the whole pretty closely.

3. Satisfactory conclusions as to the correlation of vertebrate faunas must depend on an analysis of each fauna and study of the origin and dispersal of the different groups of which it is composed. But if the more exact correlations are thus to rest on theories of dispersal, it is very necessary that they should be checked and tested at every available point, not merely by the dispersal of other groups of mammals, but by the marine faunas, stratigraphic and physiographic geology, etcetera. Otherwise we may come to such absurd conclusions as the recent solemn pronouncement of a great German authority on Proboscidea, that the American

Mastodon is of Tertiary age and did not survive into the Pleistocene, as we have erroneously supposed.

4. There are certain groups whose phyletic history is much clearer and less complex than others, and whose evolution has involved greater structural change and more rapid progress toward an extreme of specialization. These will naturally afford better evidence for correlation than more conservative groups.

5. As we have generally to deal with fragmentary material, there are some portions that show the structural changes better than others. The cheek teeth of mammals are in general far more characteristic than any other parts. In particular those phyla in which the evolutionary changes in molar and premolar teeth are in the direction of a more complex structure are of most value, as the characteristic construction can be more surely distinguished from parallel adaptations in other races of the same stock or convergent adaptations from other stocks.

6. Groups of wide geographic dispersal are more useful in correlation than those of more restricted range.

For all the above reasons the Equidæ or fossil horses are the most useful of all mammals in Tertiary correlation. Their evolution and dispersal is a comparatively simple record and has been more thoroughly studied than in any other group. The cheek teeth have a characteristic pattern, highly complex in all the later stages. They have a wide geographic range and a long geologic record and are very common and widespread. I am disposed to regard the successive stages of North American Equidæ as affording a standard of correlation for our Tertiary horizons, in the same way that the Ammonites do for the marine Mesozoic horizons.

Next to the Equidæ come the rhinoceroses, proboscideans, and various artiodactyl groups. These are less characteristic in tooth pattern and their evolutionary record is more complex and less clearly understood. Fossil Carnivora are less satisfactory because of their comparative scarcity and because the simple construction of their cheek teeth renders it more difficult to distinguish between parallelism and direct affinity on the evidence of fragmentary material. In fossil rodents parallelism is very prevalent and confusing, and there are many primitive survivals to complicate the problem. These and other fossil mammals afford corroborative evidence of varying importance.

Taking the Equidæ as a standard, we find that there are none recorded from the Paleocene or earliest Tertiary. None of the Paleocene ungulates are directly ancestral to the Eocene horses.

All Eocene horses are four-toed, with short-crowned teeth. All Oligocene horses are three-toed, with short-crowned teeth. All Miocene horses

are three-toed, with progressively long-crowned teeth. All Pleistocene horses are one-toed, with very long-crowned teeth. The Pliocene horses are less perfectly known, but intermediate in type. But these are broad generalities. Ten faunal zones are readily distinguished in the American Tertiaries, each characterized by the first appearance of a distinct generic stage of Equidæ. In some instances the progressive evolution of the stage is traced through gradual transition; in others it appears more abruptly. The older genera in several instances continue along with the newer stages, paralleling them, but less progressive or divergent in their adaptation. The emphasis must be placed, therefore, on the first appearance of a genus, not on its extinction. A single upper molar or premolar of a Tertiary equid can usually be positively identified as to genus; the lower molars are somewhat less certainly determinable.

Various other groups of mammals corroborate this series of life zones so fully and exactly that the evidence is beyond question. Their genera are not always so exactly limited in range; they are not always so certainly recognizable from fragmentary material. And in none is so long and continuous a sequence of evolutionary stages traceable. But the succession of Tertiary life zones in the continental formations of North America may be considered as firmly and permanently fixed.

The correlation of these zones with the marine Tertiaries, and in particular with the European standard of nomenclature, is somewhat less positive and precise. It must be recognized, in the first place, that the European standard is not as definitely and precisely fixed as one could wish. European geologists are not in accord as to exactly where the lines should be drawn in the marine succession between the different Tertiary epochs; they are still less in agreement as to the exact correlation between the marine and the terrestrial faunas of western Europe, and the succession of the terrestrial faunas of Europe is not so clearly demonstrated by stratigraphic evidence as it is in this country. Were these points definitely cleared up, it would be practicable to make very precise final correlations between the European and American Tertiaries. As it is, there is a certain amount of libration according as we accept one or another European authority for the standard. While I believe that our American nomenclature must needs conform to the European standards, so far as those standards are fixed and universally agreed on, yet I think that the more exact zonal division might well be based on American standards, where, as in this instance, the succession is more exactly and certainly shown than in Europe.

The correlation with the marine succession in this country is not so satisfactory. In the East we have a small mammalian fauna of Oligocene

age found in littoral Miocene beds of New Jersey, and a Pleistocene fauna said to be intercalated between Pliocene marine beds. In Texas Doctor Dumble has recently discovered a Middle Miocene mammal fauna in Pliocene marine beds. In California Doctor Merriam finds Middle or Upper Miocene mammals in a Lower Miocene marine horizon. If the marine beds are to be taken as standard, then mammalian faunas are wholly unreliable as evidence of age; for the evidence on the Atlantic and Gulf coasts would tend to pull them up in the Tertiary succession, on the Pacific coast to pull them down. It may indeed be supposed that the Pacific coast mammal faunas, being nearer to the dominant center of dispersal of the mammals, were precocious, and hence appear younger, and that those of the Atlantic and Gulf coasts were primitive survivals, and hence appear older than their true age. The alternative, assuming that the marine correlations are accurately made, is that the Atlantic marine fauna is precocious or the Pacific marine fauna retarded in the same way as has been considered possible for the terrestrial faunas. But I cannot find that the paleontologists dealing with marine faunas have considered this point seriously; and the discrepancies will probably be reduced, if not altogether removed, in most of the instances cited by a more thorough study of the stratigraphic relations.

In considering this subject of principles of correlation, I have taken up a somewhat different aspect of the subject from the preceding speakers. Doctor Ulrich and Doctor Schuchert have considered especially the *classification* of the geologic record, and have laid stress on the value of the great diastrophic movements, the shifting of strand-lines, and the characteristic succession of changes in paleogeography as the fundamental basis for this classification. Without question, we have all been much impressed with the weight of the evidence and with the force of the reasons they have presented for this view. While I cannot in this matter speak for vertebrate paleontologists in general, yet many of us would be very ready to agree that we have here, at least in theory, a sound basis for the classification of the major divisions, systems, and periods.

But the following discussion deals not with classification, but the correlation of the sequences of strata in different regions in different parts of the world. This is the preliminary work that must precede any general classification. It can be accomplished only through the fossil record. There are at present no other practical means of making the necessary comparisons. The value of fossil vertebrates in this aspect of correlation and the methods which are or should be employed in making use of their evidence form the subject of the following discussion.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PRINCIPLES GOVERNING THE USE OF FOSSIL PLANTS IN GEOLOGIC CORRELATION [1]

BY F. H. KNOWLTON

(Read before the Paleontological Society August 3, 1915)

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INTRODUCTION

Although it may already have been more ably done by the preceding speakers in this symposium, a brief outline of the general underlying principles may not be wholly out of place as an introduction to the topic assigned me.

Classification is the orderly grouping together of those beings or things that have certain characteristics in common. Correlation is the more or less technical designation employed in geology for the establishment of an orderly relationship between the geologic units of separate areas or regions. Back of all this is the desire to establish a geologic chronology or time scale—that is, a properly subordinated sequence of geologic events. When such a time scale has been established for a limited area as well as the perfection or the imperfection of the geologic record will permit, it becomes a large and important part of the work of geology to carry that record into near-by and ultimately more and more remote areas—that is,

[1] Published by permission of the Director of the United States Geological Survey.

This paper, read at the summer meeting of the Paleontological Society held at the University of California, August 3, 1915, was the concluding one in the symposium entitled "General consideration of Paleontologic criteria used in determining time relations."

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to correlate the one with the other. Of the two sets of criteria that must supply the basic data for correlation—namely, the physical and the biological criteria—the latter is by far the more important, and it is safe to say that without its aid there never could have been established anything like a rational chronology and system of correlation. To prove that this is in general true, we have only to review the earlier history of geology to find the pathway strewn with what now seem very crude and imperfect conceptions of the sequence of events, and when the attempt was made to carry this sequence, based only on physical criteria, into other areas its inadequacy became strikingly apparent. It is not to be implied, however, that the physical criteria are absolutely without any value, for in not a few cases they are the only data available and, perforce, the most must be made of them. Nor, on the other hand, is it to be affirmed that the biologic criteria are infallibly to be relied on in all cases, but rather of the two sets the latter has been found to be of most practical value. The truth of the matter is that not *one* but *all* possible sources of information must be brought under tribute in our attempted solution of these intricate problems, and when this has been done substantial harmony will result. For instance, if the two, or even three, types of biologic data are in apparent disagreement, we may rest assured that it is not necessarily the several kinds of fossils that are at fault, but rather our faulty interpretation of them.

Standard Sections

The establishment of a standard section is an essential basis for geologic correlation, and, as might be presumed from the nature of the controlling factors, the marine section has been found to give the best results, since long-continued, relatively stable environmental conditions are oftener to be met in marine deposits than in any other class of sediments. At first, and indeed for many years, it was supposed that each unit was characterized by an assemblage of life forms that were more or less completely confined to it; but as knowledge progressed, what at first appeared to be a very disconcerting discovery was made, namely, that in an increasing number of cases it was found that a fauna might recur, in a greater or less degree of purity, at a second, a third, or exceptionally even at a fourth, horizon above where it first appeared. This condition of affairs was at first very disconcerting, since it seemed to undermine the very foundations of stratigraphic paleontology; but subsequent critical study has shown that it is not so serious as it at first seemed, for while a very large proportion of the species of a marine fauna may sometimes "come back," careful study discloses that there are always detectable differences—in

other words, it never comes back pure. The close student soon learns to detect the several invasions with unfailing accuracy.

Recurrent Floras unknown

Recurrent floras in any way comparable to the above-described recurrent faunas are not known. Perhaps the nearest approach to this is where certain living plants have partially reoccupied areas from which they were forced by the Pleistocene glaciation, but throughout geologic time they have not "come back" when once excluded from an area. The reason for this is that there is no great, stable, evolutionary cradle—like the ocean—out of which they could migrate and to which they could return on the approach of unfavorable conditions, and from which they could again emerge on restoration of propitious surroundings. It is, of course, true that types of vegetation have continued for varying lengths of time, some even from their earliest known appearance to the living flora, and hardy individual species have often persisted from one epoch into another; but floras once they have disappeared from a region never return to it—they have disappeared forever. This fact undoubtedly adds much to the efficiency of plants in geologic correlation.

Rapidity of plant Migration

The proposition was long ago advanced that because an identical, or practically identical, flora appeared in two widely separated regions that this was *prima facie* evidence that it could not be of the same age in the two places, since, it was argued, it must have taken an appreciable length of time to pass from one area to another. This is not believed to be a valid contention, when we take into consideration the known rapidity with which living plants are disseminated. A few examples will serve to make the point plain. The entire vegetation on Krakatau, a volcanic island in the Indian Ocean, 30 miles from the main land, was absolutely destroyed in August, 1883. Within three years it was found that at least 20 species, including bacteria, diatoms, blue-green algæ, ferns, and flowering plants, had gained a new foothold, and within 25 years nearly 150 species had reached the island, and the typical tropical jungle was restored. The so-called Russian thistle (Salsola Tragus) was introduced into the Dakotas about 1883, and within 10 years had spread over practically all the Rocky Mountain States.

A striking example of the migration of a living shell has been worked out by Ulrich. *Littorina littoria* is known to have spread along the At-

lantic coast from Halifax to Cape May, a distance of over 700 miles, in less than 50 years, whence Ulrich concludes that "it might at the same rate encircle the globe no less than 46 times in the time-equivalent of a single Paleozoic correlation unit," and he adds: "If Paleozoic invertebrates traveled only one-fiftieth or one-hundredth as fast as this living shell, then we may reasonably assert essential contemporaneity for stratigraphic correlation extending across the continent."

Additional examples could be given, but it is thought that enough has been presented to establish the principle that identical floras in separate regions may be taken as establishing "essential contemporaneity for stratigraphic correlation." Geologic time was sufficiently long to permit such migration within the limits of any single correlatable unit, and the migration movement was sufficiently fast to have accomplished this movement many times over within such limit of time. For all reasonable correlation purposes, therefore, the colonizing of identical floras in more or less widely separated areas is practically simultaneous and their stratigraphic position essentially contemporaneous.

Use of Plants in evaluating geologic Hiatuses

It may be—doubtless is—true that the sedimentary deposition of rocks has been going on continuously in some part of the globe from the time of the earliest deposits we have knowledge of to the present; but the fact remains that a large part of the work of the geologist is devoted to detecting, describing, and properly evaluating the numerous instances in which the continuity of deposition within an area was obviously interrupted. Plants may be profitably interrogated as to the value of such time intervals. Then, if the plants in the beds above an unconformity are all, or even in major part, of wholly different types from those in the beds underlying the unconformity, it may mean that they existed contemporaneously in a near-by area and were admitted suddenly, "ready made," as it were, by the elimination of a barrier, and hence the time interval may have been of short duration. If, on the other hand, the flora in the overlying beds is of the same general type as that in the lower beds, differing only or largely in specific character, it is interpreted as meaning that the time must have been long enough for the one to have been evolved from the other and within the immediate area under consideration.

The floras in the beds just below and just above what is taken to be the line separating the Cretaceous from the Tertiary in the Rocky Mountain area offer a case in point. The beds below the unconformity (Montana, Laramie, etcetera) contain a flora of about 350 species, while the beds

above (Raton, Denver, Dawson, Lance, etcetera) have a flora of over 700 species. About 90 per cent of the Cretaceous flora was wiped out by the diastrophic activities believed to have occurred at the close of the Cretaceous, yet the flora in the beds above the unconformity consists of the same general types, many of the genera being identical. This shows that the Tertiary flora did not come in "ready made," but is presumed to have been evolved on the ground from the remnants of its Cretaceous ancestors, and this is interpreted as a confirmation of the value of the unconformity, for it must have taken considerable time to have accomplished the evolution indicated.

Method of Correlation by fossil Plants

Having set forth above a number of general principles that may be said to form the basis of stratigraphic correlation by plants, we may now detail the actual practical steps that may be taken in establishing such correlation. The first step to be taken in correlation by fossil plants is the matching of species and genera, and, since it has been shown that recurrent floras are not known, this is believed to be essentially reliable. The statement made by Ulrich[2] regarding correlation by faunas is wholly applicable to correlation by floras. On this point he says:

> "The degree of similarity exhibited by geographically separated faunas is usually proportionate to their respective ages. If great, then the evidence is provisionally accepted as indicative of essential contemporaneity."

When a collection of fossil plants whose stratigraphic position is not known is found to contain a very considerable proportion of forms identical with those from a known horizon, the presumption is that the two are essentially identical in age. Thus, when it is disclosed that over 47 per cent of the flora of the Knoxville formation is also present in known Jurassic beds in various parts of the world, the conclusion is justified that the part of the Knoxville containing this flora is also of Jurassic age. This is further emphasized by the fact that in the remainder of this flora there is nothing that is incompatible with its being of Jurassic age. When 40 per cent of the described Denver flora is found represented in the Raton flora, it is believed to indicate essential contemporaneity.

As a part of the process of matching fossils mention may be made of so-called guide or key fossils—that is, single species that experience has shown to be confined to a particular horizon or other limited stratigraphic unit. Such a fossil, or preferably two or three of similar import, is of

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[2] E. O. Ulrich: Bull. Geol. Soc. Am., vol. 22, 1911, p. 508.

the greatest value in indicating the age correlation of a horizon of previously unknown or uncertain position. The discovery of such a guide fossil immediately suggests lines of search for additional corroborative data.

It need hardly be pointed out that the presence of a single specimen, perhaps only a mere fragment, may be relied on to indicate the larger units in the time scale. Thus the finding of *Lepidodendron* or *Sigillaria* indicates that the beds containing them are older than Mesozoic, the presence of a dicotyledon that the beds are Cretaceous or younger, or the finding of a *Dictyophyllum* that the age is older Mesozoic, etcetera.

It is perhaps also unnecessary to call attention to the fact that the study of fossil plants—or all fossils for that matter—should not be permitted to foster neglect in securing all possible stratigraphic aid, for, as Ulrich has well said, "Systematic paleontology without a stratigraphic basis is regarded as an absurdity." Each complements and supplements the other, and when the story is read aright there will be found to be no conflicts or essential disagreements.

In conclusion, the writer may perhaps be pardoned a moment of retrospect over the accomplishments of paleobotany during the last quarter of a century. At the beginning of that period the study of fossil plants had small part in the councils of stratigraphic geology, but since that time, thanks to a small but earnest body of workers in all parts of the world, it has come to be a recognized and, it is believed, a respected integral part of the greater science of stratigraphic paleontology. It is not claimed that it is the golden key that is to unlock all the mysteries of geologic history—nor for that matter is any of the other of the 57 varieties into which the vast subject is now divided—but, within its proper and legitimate limit, it is believed to have won for itself a "Place in the Sun!"

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SILURIAN FORMATIONS OF SOUTHEASTERN NEW YORK, NEW JERSEY, AND PENNSYLVANIA[1]

BY CHARLES SCHUCHERT

(Presented before the Paleontological Society December 30, 1914)

CONTENTS

INTRODUCTION

The object of this paper is to show that the Shawangunk grit and conglomerate holds the position of the Medina sandstone and equivalent formations which together throughout the Appalachian region occur at the base of the Silurian system of strata. The Shawangunk-Medina formations have overlying them, in unbroken sequence, as one gets about 30 miles from the main eastern outcrops, the Clinton shales. Then

[1] Manuscript received by the Secretary of the Geological Society August 10, 1916.
This paper was presented in abstract under the title "Shawangunk formation of Medina age."

everywhere follows a great break in deposition, for all of the higher Niagaran is absent—that is, the equivalent of at least all of the Lockport and Guelph. Overlying the Clinton or the Shawangunk-Medina, in disconformable contact, is a thick shale series that below is usually of a red or pink color, and above passes into calcareous shales or ribbon limestones, the natural cement rocks of the northeastern Appalachian area. The latter, or Cayugan series, appear to go unbroken into the Lower Devonian, and yet where the contact between them is well exposed the Helderbergian is seen to begin with crystalline crinoidal or knobbly limestone, easily distinguishable from the water limestones of the Silurian system. It is probable that this contact is also disconformable, but the break is of far less significance than that between the Clinton and Cayugan.

Part I

HISTORICAL STATEMENT

Mather[2] was the first geologist to describe the Silurian formations of southeastern New York as represented by the Shawangunk conglomerate and the higher red beds, now known as the High Falls shales, but he did not succeed in correlating either with the Silurian of western New York. His conclusion was: "The observations made do not render it certain whether these red rocks are equivalent to the Onondaga salt group [the Salinan of the present paper] or the Medina sandstone; but it is thought probable, from some of the mineral characters, no fossils having been seen, that they belonged to the epoch of the Medina sandstone, and that the subjacent Shawangunk grit is equivalent to the gray sandstone [=Oswego of the Ordovician] instead of the Oneida conglomerate [now known to be a phase of the Medina]."

The formation name Shawangunk was first used by Mather, who based it on the "white rocks" (= Shongum) of the Indians and the mountains of this name that extend from near High Falls, in Ulster County, New York, southwest through Orange County and through New Jersey into Pennsylvania. These strata in the northeast rest with an angular unconformity on the Hudson River series of the Ordovician, but south of New York the contacts are conformable.

Although no fossils were found in the Shawangunk until recent years, by general consent it was held to be the eastern representative of the Medina of western New York. Accordingly the higher red shales, held to be intimately connected with the Shawangunk, were correlated with the Clinton, even though they also had yielded no fossils. These red

[2] Geology of New York, First Dist., 1843, pp. 353-355.

shales and the lower sandstones thicken rapidly to the southwest, and in Pennsylvania were also correlated with the Medina and Clinton of New York. The reasons for this age determination were based on stratigraphic position and lateral continuity, because there was no known faunal evidence. If, however, the Pennsylvania geologists had given heed to the fossils (mainly Ostracoda) that can easily be secured in the upper part of the red-beds series, they would have seen nothing reminding them of the Clinton, but rather of the Salinan and early Helderbergian series. For more than fifty years these correlations had been fixed and the formations regarded as equivalents of the Medina and Clinton. In recent years, however, it has been seen that the few fossils of the red-beds series were of Salinan time, and because the deposits were thought to be intimately united with the Shawangunk—that is, no break in deposition was seen to separate them—both were believed to belong to the same series, and hence were referred to the upper part of the Silurian system. Finally, when Clarke and Ruedemann found an abundance of eurypterids suggestive of basal Salinan forms (Pittsford) in the middle of the Shawangunk, the evidence seemed conclusive that both deposits must be regarded as of late Silurian time. Accordingly, for nearly ten years we have been so teaching our students in geology; but one day one of these young men, Walter A. Bell, greatly surprised his teacher by pointing out that a slab 20 feet square in the midst of the eurypterid beds at Otisville was replete, on its under side, with the burrows of *Arthrophycus alleghaniense* (see plate 20, figure 2)! This is the guide fossil for Medina time, and the question was again raised, What is the age of the higher red beds? Since some of these strata had yielded Salinan fossils, the further question was to be answered, Where is the break in deposition—the disconformity—between them?

Hartnagel[3] was the first to suggest that the High Falls red shales are of Salina age, and as they rest apparently conformably on the Shawangunk he further concluded that the latter represent "the invading basal member of the Salina series." Grabau[4] informs us that in Ulster County, New York, the Shawangunk is continuous in deposition with the red beds above, "which proves the age of the red beds and the Shawangunk conglomerate to correspond to that of the New York Salina." Later[5] he again refers the Shawangunk and the Green Pond conglomerates of New Jersey as well to the Salinan, and he repeats this view in 1913.[6] Van

[3] Rept. N. Y. State Paleontologist for 1903, 1905, pp. 345-346.

[4] Science, Oct. 27, 1905, p. 533.

[5] Ibid., Feb. 26, 1909, p. 355; Sept 24, 1909, p. 415, and Jour. Geology, vol. 17, 1909, p. 245.

[6] Bull. Geol. Soc. Am., vol. 24, 1913, p. 480.

Ingen[7] also for a time regarded the Shawangunk as of Salinan time, though in 1910 he returns to the older view of their Medinan age. Paul Billingsley[8] likewise refers the Shawangunk to the "early Salina." T. C. Brown[9] held that the Binnewater, High Falls (the red-beds series), and Shawangunk constitute a sequence "of a normal marine transgression" and are of Salinan time. Finally, Clarke and Ruedemann,[10] on the evidence of the eurypterids, placed the Shawangunk in the Salinan series and correlated the formation with the basal member, the Pittsford shale.

It was Van Ingen who was the first to return to the older view that the quartzites and conglomerates are of Medina age. On December 27, 1910, he presented at the Pittsburgh meeting of the Geological Society of America a paper entitled "The Shawangunk grit and its facial relationships," stating that he had found *Arthrophycus* at a number of places; and, further, that the Clinton shales overlie the beds with the burrows. This paper is not yet published, and though at the time of presentation it excited considerable unfavorable comment, Van Ingen was correct. In the following year[11] he abstracts his views as follows: The Clinton iron ores in passing from west to east "change in shoreward directions to hematitic sandstones of much greater thickness and finally to red and olive quartzites, which are equivalents of part of the Shawangunk grit of the northeastern Appalachians. The conclusion is reached that the Shawangunk grit is of Medina-Clinton-Niagaran age, and all older than the Salina to which it has lately been referred."

THE MEDINA SERIES

The Shawangunk formation is usually a gray to whitish or slightly greenish, cleanly washed, thin and thick bedded quartzite that is more or less zonally conglomeratic. The pebbles are fairly well rounded, usually of vein quartz, and as a rule under half an inch in diameter, though at times and always at the base of the formation they may attain to 6 inches across. Toward the top the formation may have one or more zones of slightly reddish color, and these seem to be equivalent to the iron-ore zones of the Clinton formation that are typically developed deeper in the trough and farther away from the shore. The shale partings of the Shawangunk are usually insignificant in thickness, though at times there are many, and single beds may exceed 2 feet, and are either green or black (carbonaceous) in color. In general the Shawangunk tends to become more shaly in the upper half. When *Arthrophycus* is present, it

[7] Science, May 21, 1909, p. 830.
[8] Ibid., July 22, 1910, p. 125.
[9] Amer. Jour. Sci. (4), vol. 37, 1914, p. 474.
[10] Mem. N. Y. State Mus., vol. 14, 1912, pp. 91, 93.
[11] Science, June 9, 1911, p. 905.

always occurs on the under surface of the sandstone lying upon a shale bed. The bedding is very regular and more or less cross-bedding is usually present; channeling is a rare feature in the lower part of the formation. Ripple-markings are also present, though not common. Sun-cracking occurs rarely and only near the top of the Shawangunk, and rain-prints were not seen by the writer. Intraformational shale conglomerates are at times well developed near the upper or lower limits of a sandstone and signify the local disrupting of a thin shale bed by the storm-generated waves in this shallow-water deposit. Grains and small nodules of siderite are usually abundant and when weathered give the sandstones a spotted appearance. In the lower third of the Shawangunk there is also usually present some feldspar, along with small fragments of serpentine. To the writer all this evidence is in favor of the view that the deposits are of the shallow sea and near the shore—great shallow-water flats of moving sands in which lived, now here and now there, in great abundance, an errant annelid, *Arthrophycus alleghaniense,* similar to the lob-worms of the English sand beaches. On the mud bottoms the eurypterids were often present in great numbers and in variety of form; usually the younger growth stages are most prevalent, though large individuals are represented by fragments. To Clarke and Ruedemann "the Shawangunk grit represents a tidal zone deposit of an encroaching sea or of a delta."[12]

These sands and conglomerates came from Appalachia to the east of the present Atlantic shoreline, then a high land of crystalline rocks elevated in late Ordovician time during the Taconic Disturbance. The rivers were long and had reduced the quartz to fine sand and fairly well-rounded, small pebbles, and the work of the sea waves had washed into deep water the muds, of which so little comparatively is present in the Shawangunk and Tuscarora formations. On the other hand, Grabau[13] would have us believe with him that the Shawangunk is a subaerial or torrential deposit formed entirely on dry land, and that in the rivers lived the eurypterids; their dead bodies were not only washed into these sands, but were also carried out into the sea. Brown,[14] however, holds correctly that "the fine-grained sandy character of this formation [Shawangunk] throughout the greater part of its depth is hardly consistent with the torrential theory of its origin." Its sediments "can not be interpreted as subaerial deposits of the alluvial fan type, and there is no apparent reason why they should be considered delta rather than normal shore deposits."

[12] Op. cit., p. 105.
[13] Bull. Geol. Soc. Am., vol. 24, 1913.
[14] Op. cit., p. 474.

The Shawangunk begins at Binnewater, New York, and thence continues unbroken for at least 200 miles to Rockville or Fort Hunter, on the Susquehanna River to the north of Harrisburg, Pennsylvania (see summary table, page 539). The thickness in the northeast is 170 feet or less (down to 10 feet); at Minnewaska it is 500, at Otisville 800, at Delaware Gap 1,565, at Lehigh Gap 1,250, at Schuylkill Gap 1,430, and on the Susquehanna it is at least 470, and more probably nearer 800. The greatest amount of conglomerate and the largest pebbles are in the region of greatest thickness—that is, between the Delaware and Lehigh gaps. In about 85 miles the Shawangunk has increased from 10 to 1,565 feet, or at a rate of more than 18 feet per mile; then for more than 50 miles farther along the strike it does not thin under 1,250 feet.

It should be added here that some of these upper beds are actually of Clinton time, but how much was not determined. Probably all of the pink and red zones in the Upper Shawangunk are of Clinton time. Farther southwest the formation appears to thin rapidly, but the amount can not be definitely stated. Northwestward across the strike from the Shawangunk or Kittatinny Mountains to Jacks Mountain the Medinan deposits lose their conglomerates in 40 miles, the sands are finer, there is more shale interbedded, and *Arthrophycus* is common. At Jacks Mountain it is 820 feet thick, or about 600 feet thinner than at Kittatinny Mountain to the east. Across the strike westward for 35 miles more (Tyrone Gap) the Medina has thinned to about 500 feet. On the other hand, from Shawangunk Mountain east to Green Pond Mountain, about 23 miles across the strike, a thickness of about 1,200 feet appears to be maintained, but the strata have considerably more conglomerate, the pebbles average larger, and the sand is coarser.

The annelid burrow *Arthrophycus alleghaniense* has been collected at such various levels that it may be said to be present throughout the Shawangunk (for detail see Part II). However, the burrow is not often present in the lower part of any section, but is more common in the upper half of the formation. It is the guide fossil for Medina time, not only in the eastern exposures here described, but for the sandstones of western New York as well.[15] Here the Medina can be traced into the equivalent Brassfield formation of Ontario, where it underlies the western phase of the Clinton; at Jacks Mountain, in eastern Pennsylvania, the Tuscarora, the equivalent of the more easterly Shawangunk, is overlain by the typical or eastern phase of the Clinton. These facts make it plain that the Shawangunk is of the time of the Medina, and that both formations are the deposits of the invading Silurian sea, and are characterized organically by *Arthrophycus alleghaniense* (Harlan).

[15] See Schuchert: Bull. Geol. Soc. Am., vol. 25, 1914, p. 288.

THE CAYUGAN SERIES

In southeastern New York the Shawangunk is overlain by the High Falls red shales, and the usual interpretation is that both formations are continuous in deposition. Even in the shafts in the Rondout Valley, dug by the New York City Board of Water Supply, T. C. Brown[16] describes the contact as a gradual transition, and not an abrupt change from the Shawangunk grit to the High Falls shale. However, in shaft 7 he notes that the upper 6 to 8 feet of the Shawangunk consists of a coarse conglomerate, and that this character is continued into the basal 2 feet of the High Falls shale. To the writer these 8 to 10 feet are rather to be interpreted as the basal beds of the invading High Falls shale, and the great hiatus lies below these conglomerates. Nowhere in all of the many places studied by the writer is there, however, convincing physical evidence that there is a break between the equivalents of the Medina and Salina deposits. This is due to the condition that in most places the contacts are obscured by weathering, and all that can now be said is that the contacts must be of the disconformable type, because on one side of the line the fossils of the green shales are of early Silurian time and on the other side of Salina age. Even this conclusion is not easy to establish, and this can be done only by tracing the two series of deposits from New York into Pennsylvania and Maryland.

In the various sections described in Part II of this paper it is seen that in the eastern ones the Shawangunk is always followed by a red shale formation, and that in every case the actual contact between these two series was not seen. However, just as soon as we strike westward into the deposits farther away from the shore we meet with formations intermediate in age between the Shawangunk and the Salinan series. Forty miles across the basin from Shawangunk or Kittatinny Mountain there occurs, in Jacks Mountain, above the Medina or Tuscarora, 1,043 feet of more or less greenish shales with occasional iron-ore beds, all of which have marine organisms indicative of Clinton time. In other words, as we go westward a great shale formation, intimately linked with the Medina series, is wedged in between the Shawangunk and the Salina. The writer has seen this stratigraphy in many places from New York to Virginia, and if one disregards the fossils no striking break is anywhere to be seen between the Clinton shales and the disconformably superposed Salina shales. Again, in most places the actual contacts are obscured, for they lie in the midst of two shale series. In Maryland, at Pinto, however, the contact between them is well exposed, and only on the basis of fossils, which can be had here immediately on either side of a deter-

[16] Op. cit., pp. 471, 472.

mined line, is the break to be discerned. It is this state of affairs that has perplexed and still perplexes stratigraphers.

At Rondout, New York, there is no Salina present, and 8 miles to the southwest there is from 80 to 90 feet of it. Following along the strike of the mountains, the formation thickens rapidly; so that at Otisville there is at least 800 feet, at the Delaware Gap 2,425 feet, at the Lehigh Gap 2,500, and at the Schuylkill Gap there may be 3,000 feet. In all of these places the deposits are more sandy, while farther west and away from the shore the Salina thins and becomes more and more calcareous to the southwest. In Jacks Mountain the thickness is 1,930 feet, at Tyrone 1,350 feet, and west of Cumberland, Maryland, it is 1,300 feet; the last place is about 300 miles to the southwest of Rondout.

The origin of the red color of the Salinan shales is usually ascribed to the time of deposition and is thought to be due to periodic subaerial oxidation under a dry climate—vast marine flats that were periodically dried out and sun-cracked, reducing the iron in the sandy shales to the ferric condition. It would seem that this must be the genesis for all the deep red and maroon or brick-colored shales; but as for the lighter red and pinkish shales, some at least owe their color to recent weathering and the percolating subaerial waters. Proof for the latter mode of red color origin is brought forward by Brown,[17] who says that the red color of the High Falls shale "is not an original character, but has been produced by comparatively recent weathering, and practically fails where these beds are uncovered away from the outcrop or the effects of circulating ground waters." In the deeper parts of the shafts and tunnel of the Rondout Valley the High Falls shales are green or black in color. Brown's explanation, however, can not be applied everywhere, and especially not to the brick-red shales of the Salinan series of Pennsylvania.

The fossils of the Salinan series do not occur in the red beds, but only in the yellow and blue more or less calcareous shales or in the waterlimes. In most cases the organisms are ostracods of small and large species. The smaller ones often abound in countless numbers and are mainly of undescribed species of the genera *Klœdenia* and *Klœdeniella.* The larger forms all appear to be *Leperditia altoides* and *L. alta*, which range throughout the Cayugan, and the latter even high into the Lower Devonian. On the other hand, the Clinton species are very different forms, the commonest ones being *Beyrichia lata* (a guide fossil) and the less ornate and smaller *Bollia lata.* In another year the Maryland Geological Survey will have published a monograph on the Silurian of that State, and in this the above-mentioned Ostracoda, along with the new forms, will be described and illustrated by Ulrich and Bassler.

[17] Op. cit., p. 474.

SUMMARY OF SECTIONS NEARLY 300 MILES APART

O = not present, X = present, but thickness not determined

	Cayugan.	Niagaran.				Medina.	Rich-mondian (Juniata)	Lorraine (Bald Eagle).
		Guelph.	Lockport.	Rochester.	Clinton.			
Rondout, New York (Devonian on Ordovician)	O	O	O	O	O	O	O	X
Binnewater-High Falls, New York (8 miles southwest) ..	80– 90	O	O	O	O	10	O	X
Rondout Valley, New York (5 miles west of last locality) .	90–100	O	O	O	O	170–280	O	X
Green Pond Mountain, New Jersey (east of all other localities)	200	O	O	O	....	1,200	O	X
Otisville, New York (35 miles southwest)	?800	O	O	O	O	*800	O	X
Delaware Gap, New Jersey (50 miles southwest)	2,425	O	O	O	....	*1,565	O	X
Lehigh Gap, Pennsylvania (28 miles southwest)	2,500	O	O	O	....	*1,250	O	X
Port Clinton, Pennsylvania (26 miles southwest)	?3,000	O	O	O	....	*1,430	O	X
Rockville, Pennsylvania (50 miles southwest)	X	O	O	O	?	?800	O	X
Jacks Mountain, Pennsylvania (40 miles northwest)	1,930	O	O	O	1,043	820	1,590	1,250
Tyrone City, Pennsylvania (25 miles west and 22 miles southwest)	1,350	O	O	O	1,000	500	1,090	1,320
Cumberland, Maryland (75 miles south)	1,300	O	O	O	600	290	?730	?

* Includes some Clinton.

Part II

THE SILURIAN SECTIONS

Rondout, New York.—See G. Van Ingen and P. E. Clark: Report of the New York State Paleontologist for 1902-1903, pages 1176-1227.

Devonian.

Hudson River contact (see figure 1). The contact between the Cobleskill and the Hudson River thin-bedded sandstones and shales is a markedly unconformable one. The former stands nearly vertical, while the Hudson River series dips northeast by east 48°. The two formations are of very different materials—the Cobleskill is a crystalline crinoidal limestone with many fossils—and even though the Hudson River is largely a sandstone series, yet there is no sand or conglomeratic material in the adjacent waterlime and but little sand along the contact between the two formations. Though mountains were thrown up here toward the close of the Ordovician (Taconic Disturbance), they had been reduced to a peneplain before the close of the Silurian, when the seas of Lower Devonian time again invaded the area.

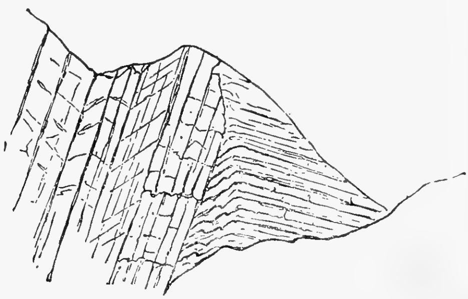

FIGURE 1.—*Contact between the Lower Devonian Waterlimes (Cobleskill) and the Hudson River thin-bedded Sandstones*

Cement quarries at Rondout, New York. After H. D. Rogers, 1859.

Binnewater-High Falls, New York.—Eight miles southwest of Rondout. See T. C. Brown: American Journal of Science (4), volume 37, 1914, pages 464-474.

Devonian. Helderbergian series. Along the Wallkill Valley Railroad between Binnewater and Rosendale the Helderbergian is exposed in steep cliffs with the strata deformed and sheared. The lowest members are seen in the first cut north of Binnewater station and about the cement mill here. In the basal 4 inches of the *Cobleskill* impure knobbly and cherty limestone there is an abundance of *Halysites catenularia*,

large stems of *Mariacrinus*, and more rarely *Stromatopora*. The corals continue downward and into the *Rosendale* waterlime (for 12 inches), here a bed 9 feet thick. Below are 3 feet more of thin-bedded, poor, water limestone with local beds of chert; the basal transition zone, 12 inches thick, is sandy, with the coarsest sand at the bottom.

The Lower Cobleskill is again well seen at the falls of the Rondout at High Falls, followed beneath by the Rosendale cement beds, about 20 feet thick.

Binnewater sandstone. North of Binnewater station this formation has a thickness of from 32 to 35 feet. It is a coarse-grained, gray, dense quartzite, easily distinguished from the formations above and especially below, and consists in the main of cleanly washed, regularly bedded, thin sandstones, with interbedded green to black shales that vary in thickness up to 4 inches. The strata are commonly rippled, with the wave crests from 1 to 2.5 inches apart. Near the middle of this member were seen sun-crackings. The uppermost 5 feet are somewhat cross-bedded and with the coarsest sand; a few *Halysites* occur, linking the formation faunally with the Cobleskill cement beds.

Farther north on the Wallkill Valley Railroad at the north end of Red Rock siding is another and better exposure of the Binnewater sandstone, with a complete transition zone into the cement beds of the Cobleskill. Here the upper beds of the Binnewater sandstone have far more lime and the terminal 3 feet have the undescribed *Favosites globuliformis* (Vanuxem) and *Stromatopora*.

At High Falls the Binnewater thin-bedded grayish sandstone is fully exposed and has a thickness of about 25 feet, though Brown gives it as 50 feet and Hartnagel as 15 feet, differences that are due to delimitations in a continuous series of sediments. Here it is also rippled, has more calcareous cement, is thinner bedded, and has zones of intraformational pebbles of waterlime-like rock (now leached out, leaving cavities), showing that near by impure limestones were forming and being torn up by the storm waves of this shallow sea.

Probable break.

Silurian. Cayugan series.

High Falls shale, about 80 to 90 feet thick. Best seen along Rondout River below High Falls, New York, where there is no clearly developed transition zone nor easily determined hiatus between it and the higher Binnewater sandstone. The upper 10 feet of the High Falls shale is a sandy and very impure blue water limestone that is much sun-cracked. This passes unbroken into brick-red shales, full of small leached cavities and with much intraformational shale conglomerate, interbedded with an occasional blue shaly waterlime (more or less sun-cracked) zone, which together have an estimated thickness of 30 feet. Then come evenly bedded, dark blue, very hard, calcareous sandstones about 12 feet thick. Below occur from 30 to 40 feet of mainly red shales, interbedded with green ones. These rest on the Shawangunk formation.

Near Binnewater the Binnewater sandstone rests abruptly on the High Fall shales, indicating, it is thought, a hiatus here in sedimentation. Here the upper part of the High Falls shales consists of green, blue, and black limy and somewhat sandy shales (12 feet), followed below by brick-red sandy shales (25 feet) that are much sun-cracked; the latter rest on 10 feet of Shawangunk conglomerate.

Great break. All of Niagaran series absent.

Silurian.

Shawangunk conglomerate. North of Binnewater 10 feet of Shawangunk is exposed in the midst of the High Falls shale. Just what the structural relation of one is to the other the writer could not determine.

The uppermost part of the Shawangunk is seen at the Rock Cliff House in High Falls. Here about 30 feet is exposed beside the road, and consists of a milky white conglomeratic quartzite with the small vein quartz pebbles (up to 1 inch in diameter) well rounded and imbedded in a clean sand. *Arthrophycus alleghaniense* was found here by Professor Van Ingen. The remainder of the Shawangunk is exposed in the gorge of the Rondout, and the contact with the High Falls shale is shown near the power-house of the Electric Light and Power Company.

Rondout Valley underground geology.—Five miles west of High Falls. A number of drill holes (cores) were put down by the New York City Board of Water Supply across the Rondout Valley, and the following description of the rocks is much condensed from Brown: American Journal of Science (4), volume 37, 1914, pages 464-474.

Devonian. Helderbergian series.

Binnewater sandstone, 52 to 62 feet thick. At the top a thin layer of hard, white, quartzitic sandstone, followed by alternating thin beds of porous sandstone and green shale that are more or less calcareous and full of small cavities. The transition downward is said by Brown to be complete into the Silurian.

Silurian. Cayugan series.

High Falls shale. Thickness averaging between 90 and 100 feet. A variable shale and pyritiferous formation. An upper shale member that as a rule is green or gray in color (27 to 37 feet thick), a middle dark to black sandy zone (12 to 15 feet), and a lower green to black shale division (40 to 50 feet). At the surface this formation is predominantly red in color, but this appears to be due largely or wholly to aerial oxidation. The cores show that the farther the formation is away from the surface the more the strata lose their red color. The transition to the underlying conglomerate is said to be a gradual one, not an abrupt contact or unconformity. However, in shaft 7 Brown distinctly notes a coarse conglomerate at the top of the Shawangunk (6 to 8 feet) and in the basal 2 feet of the High Falls shale, all of which can as well be interpreted as the invading base of the latter

series and as indicative of a break between the Lower and Upper Silurian.

Probable break here.

Silurian.

Shawangunk conglomerate. Thickness variable between 170 and 280 feet. In general the formation is a pure white quartz sandstone with zones of conglomerate that are most prevalent toward the bottom and top. There are also occasional thin zones (up to 1 foot) of green shale and black shale (less than 1 inch thick).

Ordovician.

Marked unconformity. All of Richmondian absent.

Hudson River shales.

Green Pond Mountain, New Jersey.—East of all the other localities. Based on the work of Darton: Bulletin of the Geological Society of America, volume 5, 1894, pages 382-385; Kümmel and Weller: Annual Report of the Geological Survey of New Jersey for 1901, 1902, pages 9-15; Grabau: Bulletin of the Geological Society of America, volume 24, 1913, pages 477-479; and Barrell: American Journal of Science, volume 37, 1914, pages 234-239. This area is about 23 miles to the east of Shawangunk Mountain and is the most easterly Silurian area of the Appalachian trough. The strata lie in a much folded and faulted syncline, so that it is difficult to get their exact thicknesses.

Silurian. Cayugan series.

Longwood shales. Below the Helderbergian (Decker Ferry) there occurs in Longwood Valley, east of "Middleton," a soft, sandy shale series, much cleaved, mostly of a bright red color, with interbedded lighter colored zones. The thickness is estimated at 200 feet.

Probable break. Darton describes the Longwood shales as grading into the Green Pond conglomerate, but if the former is Salina in age, as the present writer correlates it, and the latter is the equivalent of the Shawangunk, then there is a marked stratigraphic hiatus between the two, with all of the Niagaran series absent. Kümmel and Weller state that the Green Pond passes upward somewhat abruptly into the soft red Longwood shale.

Green Pond conglomerate. Consists in the main of coarse red and greenish conglomerates below and buff and reddish quartzites above. The subangular and well-rounded pebbles vary in size up to 3 inches and are embedded in a hard, sandy, quartzitic matrix of dull red color. The pebbles are "almost entirely white quartz, but some pink quartz, black, white, yellow, and red chert, red and purple quartzite, and a very few red shale and pink jasper pebbles occur." "The thickness of this formation is probably not less than 1,200 feet, and locally it may be 1,500 feet" (Kümmel and Weller).

Ordovician.

Great break. All of Richmondian absent.

Hudson River shales, or older formations.

Otisville, New York.—Thirty-five miles southwest of Rondout Valley. Section across Shawangunk or Kittatinny Mountain. See Cook: Geology of New Jersey, 1868, pages 146, 150; Lesley: Second Geological Survey of Pennsylvania, Final Report, volume I, 1892, pages 676-678, and volume II, 1892, page 733; Clarke and Ruedemann: Memoir 14, New York State Museum, 1912, pages 91, 93, 104.

Silurian. Cayugan series.

Longwood shales. A thick series of brick-red sandy shales interbedded with reddish and gray sandstones, greenish shales, and occasional very impure water limestones. All are much sun-cracked (the calcareous beds at times break out in prismatic columns; see plate 20, figure 1) and rippled. In the water limestones a few Salinan Ostracoda were seen. The basal beds of this red series are exposed at mile-post 81.25 from Jersey City on the Erie Railroad, or a little south of Graham station, some miles to the southwest of Otisville; but the actual contact with the Shawangunk was not seen. However, the relation elsewhere shows that the red shales are disconformable with the quartzite. Cook gives the thickness as at least 800 feet, but it appears to be much more.

Great break. All of Niagaran absent.

Silurian.

Shawangunk quartzite, about 800 feet thick (see plate 20, figure 2). The upper 150 feet of the Shawangunk is devoid of conglomerate and is more commonly a greenish sandy shale with more or less of red shales interbedded with yellowish and reddish sandstones. The red beds are in the middle of this zone and are sun-cracked and finely rippled, with the crests from .75 to 1.50 inches apart; here the sandstones are also thicker than they are below, ranging between 1 and 4 feet. As *Arthrophycus* occurs in the lower part of this upper zone, this part at least is also of Medina age. It should be added, however, that the uppermost beds are very near or may actually be in the transition to the Clinton. This conclusion is supported by the olive-green sandy shales that have a silky-looking surface, on which are the remains of *Buthotrephis gracilis*, a fossil that is especially common in the lower part of the Clinton. *Pterinea emacerata* also appears to be present.

The rest of the Shawangunk, 650 feet in thickness, consists of thin-bedded conglomeratic quartzites (4 to 18 inches thick), coarse in grain below and finer above, and cross-bedded throughout. In the lower 125 feet there is also considerable channeling. The pebbles are of vein quartz, subrounded, larger below, but averaging .25 inch throughout the greater part of the Shawangunk. Below, the sandstones are dark in color, probably due to admixtures of the Hudson River shales; but upward they are lighter in color and of greenish white cast. Interbedded are many lenses of black shale, varying from .25 to 6 inches thick, with the greatest amount near the middle of the forma-

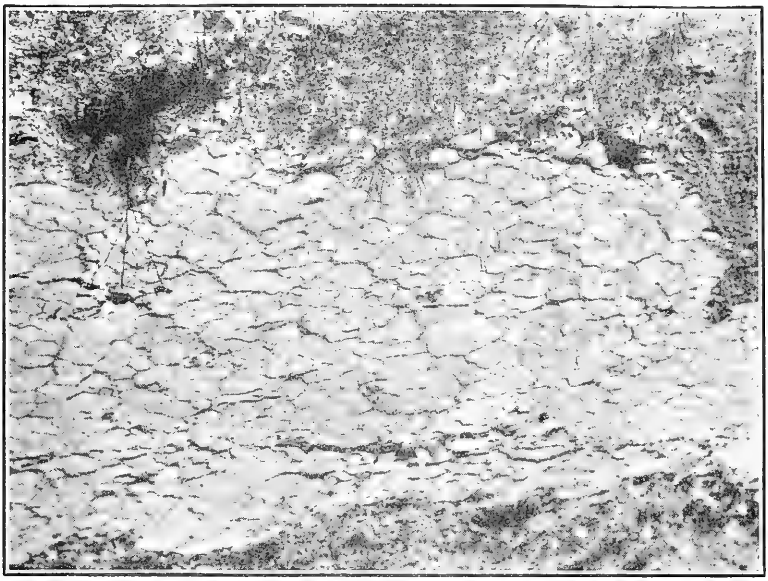

FIGURE 1.—SUN-CRACKED, LIMY LOWER SALINA SHALE, NEAR GRAHAM, SOUTHWEST OF OTISVILLE, NEW YORK

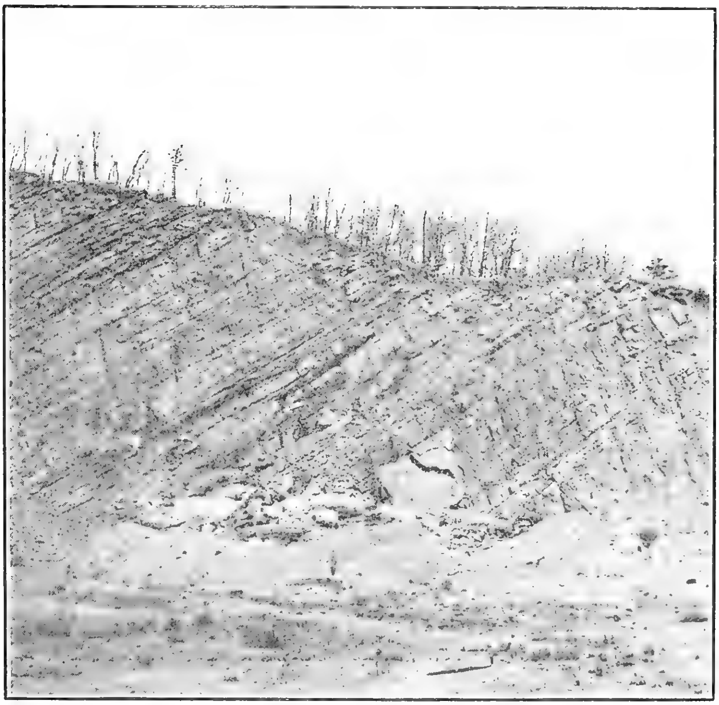

FIGURE 2.—GREAT BALLAST QUARRY IN THE SHAWANGUNK, NEAR OTISVILLE, NEW YORK

The large vertical slab is replete on the under side with *Arthrophycus alleghaniense*

SALINA AND SHAWANGUNK AT OTISVILLE, NEW YORK

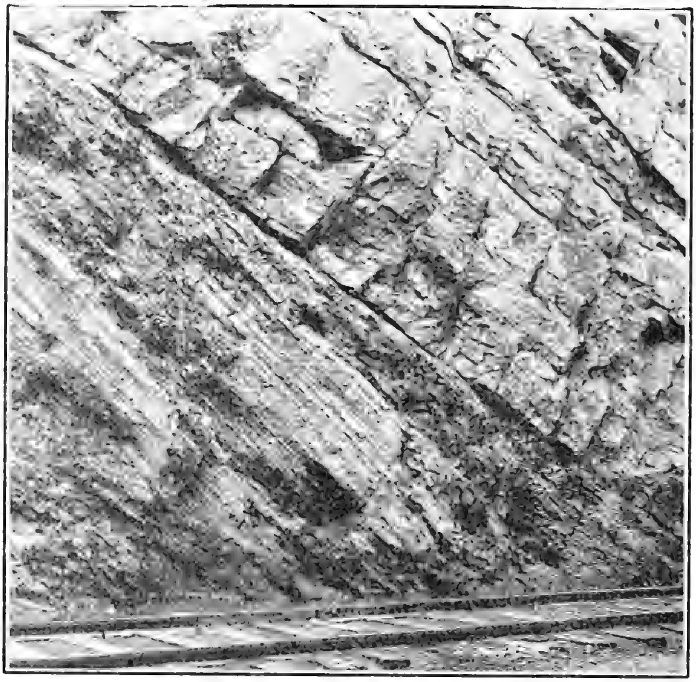

FIGURE 1.—UNCONFORMABLE CONTACT BETWEEN THE HUDSON RIVER SANDY SHALES AND THE SHAWANGUNK IN RAILWAY CUT WEST OF OTISVILLE, NEW YORK

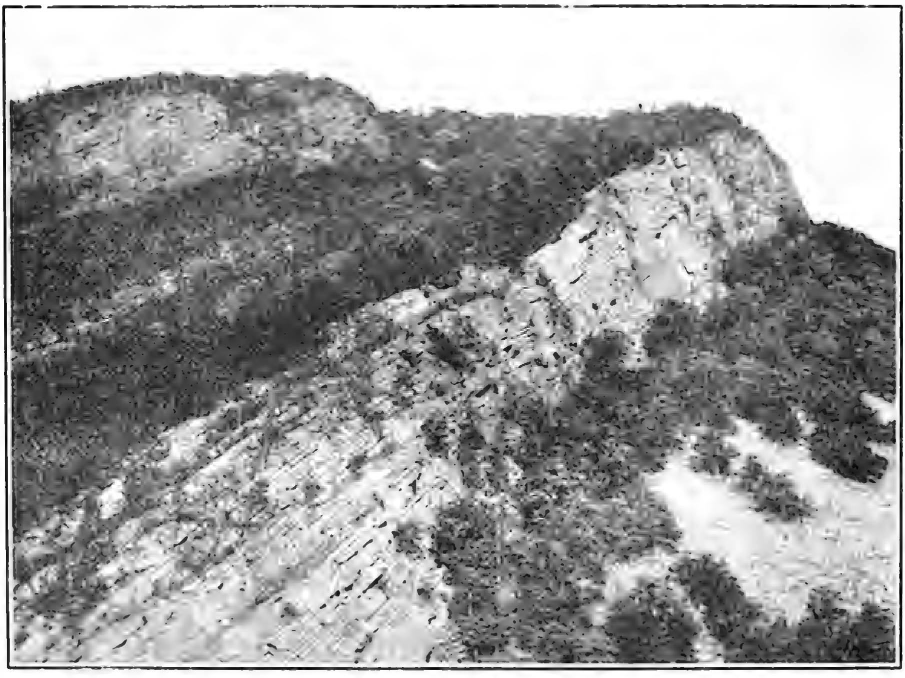

FIGURE 2.—THE SHAWANGUNK AND TALUS-COVERED HUDSON RIVER SHALES ON NEW JERSEY SIDE OF THE DELAWARE GAP

SHAWANGUNK QUARTZITES OVERLYING HUDSON RIVER SHALES

tion. All of the sandstones have grains and small nodules of siderite that on weathering give them a more or less spotted appearance. This feature is most marked at Otisville, but is also seen elsewhere.

The basal 7 feet of the Shawangunk is a conglomerate, with the quartz pebbles ranging between .75 and 1.25 inches; there is also an occasional one of the Hudson River sandstones. The contact with the Hudson River is unconformable.

Shawangunk Mountain continues from Otisville northeast for 45 miles and ends abruptly at Rosendale. At Otisville the thickness of the Shawangunk is 800 feet, and 24 miles to the northeast, at Minnewaska, it is reduced to 500 feet (Grabau). Farther north Mather states that it thins to 150 and finally to 60 feet.

Arthrophycus alleghaniense occurs in greatest abundance at 420 feet above the Hudson River shales (see plate 20, figure 2). At this level there are a number of black shales and these have the eurypterids described by Clarke and Ruedemann (*Eurypterus maria, Eusarcus (?) cicerops, Dolichopterus otisius, D. stylonuroides, Stylonurus (Ctenopterus) cestrotus, S. myops, Hughmilleria shawangunk,* and *Pterygotus (Erettopterus) globiceps*). Another zone of burrows occurs at 650 feet above the base of the Shawangunk and a third at 750 feet. It is probable that others were seen at about 100 feet above the base.

Ordovician.

Great break. All of Richmondian absent.

Hudson River series. For contact with Shawangunk see plate 21, figure 1. Has small *Climacograptus bicornis* in abundance. A series of dark green laminated shales with, rarely, a zone of graptolites. The dip is 41° northwest, strike north 41° east, while the superposed Shawangunk has dip 34° northwest, strike 41° east, magnetic. From this we learn that the Taconic foldings so pronounced at Kingston have nearly died out in the 45 miles between these two places.

Delaware Gap, New Jersey-Pennsylvania.—Fifty miles southwest of Otisville. The following observations are made from the exposures on both sides of the Delaware River through Kittatinny Mountain. See Rogers: Geology of Pennsylvania, volume I, 1858, pages 126-130, 271, 277, plate at end of volume; Cook: Geology of New Jersey, 1868, page 146; Lesley: Second Geological Survey of Pennsylvania, Final Report, volume I, 1892, pages 634, 638, 641, 675; also Report G6 of the same series.

Silurian. Cayugan series. This is the Clinton series of the Second Geological Survey of Pennsylvania Reports and is given as 2,425 feet in thickness; Grabau (Bulletin of the Geological Society of America, volume 24, 1913, page 478) gives it as over 2,300 feet. The series is not fully exposed, but appears to be made up of red shales and argillaceous red sandstones in beds from 2 to 20 feet thick, interbedded with many beds of green, coarse and much cross-bedded quartzites varying between 2 and 6 feet in thickness. The latter appear to be river ma-

terials of a delta and they often cut more or less deeply into the red shales. The latter are much cleaved and slaty, and there are many zones with vertical holes that are interpreted as due to capillary pipes through which the ground waters were raised to the surface, due to the dry climate of the time. In the upper portion there is, rarely, an argillaceous limestone with hemispheric bryozoa. Toward the bottom sandstones are more prevalent and appear to make the base of the Salinan series.

Great break. All of the Niagaran absent.

Silurian.

Shawangunk quartzites (see plate 21, figure 2). The succession is not all exposed. The Second Pennsylvania Survey gives the thickness as 1,565 feet, but Grabau (loc. cit.) gives it as 1,900 feet. Twenty-three miles to the northeast he says it has thinned to 1,500 feet. The formation begins at the base with cleanly washed, white, coarse-grained, heavy-bedded, somewhat conglomeratic quartzites. The rest of the formation consists of thin-bedded, less cleanly washed, dark greenish sandstones, with innumerable zones of vein quartz conglomerates (about 80 per cent of the formation). The pebbles vary between .25 and .50 inch in diameter. Associated with the quartz pebbles are others of a black shale in flat pieces, and in sizes up to 5 inches. These are of a intraformational character, as they are derived from the mud layers broken up by the storm waves or the undertow. There are also interbedded many dark green to black shale zones that vary in thickness up to 2 feet or more. All in all, the Shawangunk here resembles that of Otisville, only it is darker in color and with far more and larger intraformational shale pebbles.

Arthrophycus alleghaniense can be had on the New Jersey side at 225 feet above the base just above a black shale bed 10 inches thick. Another zone occurs 10 feet higher, and apparently also at 75 feet above the base, where the first black shale bed appears. Rogers (1858) reports this fossil very rarely in the upper portion of the Medina here. Van Ingen states (Memoir 14, New York State Museum, 1912, page 417) that at about 735 feet above the Hudson River shales, or in about the middle of the "White Medina conglomerate No. 2" of the Pennsylvania Survey, he collected an abundance of eurypterids (the Otisville fauna) in thin seams of black shale. The species are *Eurypterus maria, Dolichopterus otisius, Stylonurus* cf. *myops, Hughmilleria shawangunk,* and *Pterygotus* cf. *globiceps.* The same eurypterids occur in the Swatara Gap, Lebanon County, Pennsylvania, associated with *Arthrophycus alleghaniense* (ibid., pages 418-419).

Ordovician.

Great break. All Richmondian absent.

Hudson River shales. At the southeastern end of the gap on the Pennsylvania side is shown the contact between the Hudson River series and the Shawangunk. The contact is of the disconformable type. The

Hudson River series consists of blue-black shales with about one-half of the formation made up of thin and thick interbedded dark quartzites. No fossils were seen.

Lehigh Gap, Pennsylvania.—Twenty-eight miles southwest of Delaware Gap. See Rogers: Geology of Pennsylvania, volume I, 1858, page 273, and plate at end of volume; Lesley: Second Geological Survey of Pennsylvania, Final Report, volume I, 1892, pages 641, 674; volume II, 1892, page 731; also Report G6 of the same series.

Silurian. Cayugan series. This series is seen to best advantage on the north side of the river, in the vicinity of Lehigh Gap station of the New Jersey Central Railroad. H. D. Rogers gives the thickness as about 1,630 feet; the Second Pennsylvania Survey as 1,275 feet, and adds that it may be as thick as 3,275 feet. Grabau (op. cit., page 482) gives the thickness as nearly 2,500 feet. The greater part of the series consists of brick-red and greenish sandy micaceous shales and fine-grained sandstones, somewhat rippled and sun-cracked. The lower 85 feet consist of thin and heavy bedded, greenish yellow sandstones with thin shale partings; the basal sandstone is 10 feet thick. The series rests disconformably on the thinner bedded and more glossy Shawangunk and may be seen along the wagon road and elsewhere in the vicinity of the station.

Great break. All of Niagaran absent.

Silurian.

Shawangunk formation. Can be studied to best advantage along the railway cuttings and wagon road on the north side of the river between the Ordovician exposures and the Chestnut Ridge Railroad. The total thickness appears to be nearly 1,250 feet; Rogers (on plate at end of volume) gives it as between 1,200 and 1,300, and the Second Pennsylvania Survey as 1,125 feet.

The Upper Shawangunk, 900 feet in thickness, is devoid of conglomerate and consists of the following zones, going downward in the section: (1) Light green shales (weathering to yellow, with silklike surfaces; the same character pertains to most of the other green shale zones) and sandy red shales, interbedded with three thick quartzites (70 feet); (2) greenish shales interbedded with thin beds of coarse greenish quartzites (150); (3) red shale zone (12). These three upper zones may be equivalent to some part of the Clinton. (4) Thin-bedded quartzites (8); (5) greenish shales (20); (6) curly shaly sandstones (10); (7) greenish sandstones and shales with an occasional thin red shale bed (40); (8) covered area (190); (9) thin and thick bedded sandstones (25); (10) covered area (100); (11) thin-bedded sandstones and greenish shales with an occasional black shale (175); (12) covered area (100).

Near the bottom of this Upper Shawangunk series, or about 600 feet above the Hudson River contact, Professor Barrell collected a specimen of *Arthrophycus alleghaniense.* It was found on the south side

of the river along the upper railway cutting. It should be added here that the higher strata of this Upper Shawangunk may actually be of early Clinton time, a correlation suggested by the physical nature of the strata (as at Otisville) and by the presence of *Buthotrephis gracilis* Hall.

Lower Shawangunk. Thin-bedded greenish and conglomeratic clean quartzites, with very thin shale partings, 350 feet thick. Vein quartz pebbles are all small, decreasing in size upward. Thick and thin bedded, abundantly conglomeratic, cleanly washed quartzites, with or without shale partings, as follows: (1) Thin-bedded, greenish sandstones, with thin shale partings (157 feet); (2) Dark colored, thick bedded, conglomeratic quartzite with small and large vein quartz pebbles (40); (3) light colored, heavy-bedded quartzite with dark zones but without conglomerate (65); (4) thick-bedded, dark quartzite with an abundance of thin and thick conglomerate zones with the vein quartz pebbles large, and among them many of black flint (?Cambrian age), some of black shale and very rarely one of serpentine (80). The basal 8 feet are made up of (1) rotten quartzite with large, well rounded quartzite pebbles, probably of Cambrian age, and more rarely vein quartz pebbles (6); (2) a pebble bed as before with the stones ranging up to 6 inches across (18 inches), and (3) rotten sandy shales (6 inches). The contact with the Hudson River is disconformable.

E. T. Wherry (Science, September 24, 1909, page 416) reports "two small areas of Shawangunk conglomerate, preserved by down-faulting some 20 miles south of the main exposure in the Blue Ridge [of the Lehigh Gap], corresponding in position and lithologic character to the Green Pond of New Jersey."

Ordovician.

Great break. All of Richmondian absent.

Hudson River formation. Greenish sandy shales with zones of thin-bedded sandstones. At 25 feet and 75 feet beneath the Shawangunk occur sparingly *Diplograptus foliaceus* var. *vespertinus* Ruedemann.

Schuylkill Gap at Port Clinton, Pennsylvania.—Twenty-six miles southwest of Lehigh Gap. See Second Geological Survey of Pennsylvania, Final Report, volume I, 1892, pages 632, 643, 673; volume II, 1892, page 733; also Report G6 of the same series. The geology in this gap of the Little Schuylkill River is much complicated by folding, and especially by faulting; so that the detail is not easily made out.

Silurian. Cayugan series. The Second Pennsylvania Survey gives the thickness of these red beds as about 3,000 feet.

Great break. All Niagaran absent.

Silurian.

Shawangunk formation. The Second Pennsylvania Survey gives the section as follows:

	Feet
Upper Medina gray sandstone	90*
Iron-stained sandy shales	480*
Lower Medina white sandstone	60
Iron-stained sandy shales	600
Oneida white sandstone and gravel beds	200
	1,430

* A part of this thickness is to be regarded as of Clinton age.

The stratigraphic succession here appears to be very much as in the Lehigh Gap, only that the Upper Shawangunk is even more thin-bedded; near the top recur the Medina red beds that are probably of Clinton age, though no Clinton fossils were seen. The Lower Shawangunk consists of grayish white, heavy and cross bedded quartzites. The conglomerate is restricted to the lower 8 feet, where the pebbles range in size up to .75 inch. Higher in the formation they are restricted to the bedding planes.

Arthrophycus alleghaniense was seen at 4 feet and at 90 feet above the base of the Shawangunk.

Ordovician.

Great break. All of Richmondian absent.

Hudson River shales. Well exposed here, but the contact with the Shawangunk is faulted.

Susquehanna Gap at Rockville (= Fort Hunter), Pennsylvania.—North of Harrisburg and 50 miles southwest of Port Clinton. See Second Geological Survey of Pennsylvania, Final Report, volume I, 1892, pages 637, 643, 669-673; volume II, 1892, page 735.

Silurian. The Silurian is here overturned and thrusted on itself to the eastward over the Hudson River series, and the thicknesses given are therefore not at all reliable. Regarding this, Lesley writes as follows: "Following the mountain only a few miles eastward from the Susquehanna to where the beds of number IV lean in their natural attitude (dipping north), the formation becomes of its usual thickness; and following the mountain westward from the Susquehanna not more than 15 miles, the usual thickness of the formation is again resumed. We have, therefore, some right to ascribe its abnormal thickness at the Susquehanna to the overturn" (639).

Shawangunk formation. The upper shaly and thin-bedded white Shawangunk with greenish shale partings is said by the Second Pennsylvania Survey to have a thickness of between 300 and 400 feet, and consists of greenish-grained quartzite devoid of pebbles. The lower sandy thin-bedded and conglomeratic Shawangunk appears to vary between 60 and 70 feet. The basal beds resting on the Hudson River shales consist of conglomerate; the upper 10 feet with the pebbles ranging up to .75 inch and the basal 5 feet consist of quartzite pebbles averaging between 2 and 3 inches. The probable thickness of the entire Shawangunk here may be 800 feet.

Ordovician.

Great break.

Hudson River shales. The contact here is like that to the northeast, with all of the Richmondian absent. The next section to be described, Reedsville, is 42 miles across the strike to the west and in the deeper part of the Appalachian geosyncline. In this interval there appears an additional sandstone formation of great thickness that is correlated with the Richmondian and has a thickness of about 1,590 feet. It lies above the Hudson River equivalents and beneath the Medina (Tuscarora).

Jacks Mountain, Pennsylvania.—In Kishacoquillas Gap, between Reedsville and Yeagertown, 40 miles northwest of Rockville. This is to the west of Lewistown. See Rogers: Geology of Pennsylvania, volume I, 1858, page 473; Lesley: Second Geological Survey of Pennsylvania, Final Report, volume I, 1892, pages 640, 645, 651-653; volume II, 1892, pages 787-799.

Silurian. Cayugan series.

Bloomsburg formation. Total thickness of the "red Clinton," according to the Second Pennsylvania Survey, 1,930 feet. Their terminology and erroneous correlations are as follows: (1) Waterlime shale (470 feet); (2) Salina variegated shale with Ostracoda (358); (3) Niagara limestone (3 feet 5 inches); (4) Niagara shale (70); (5) Clinton Upper Red shale (432 feet 4 inches); (6) Clinton Upper lime shale (325 feet 5 inches); (7) Clinton Lower red shale (270 feet 8 inches).

Great break. Most of Niagaran series absent.

Silurian. Niagaran series. Total thickness about 1,043 feet. A shale formation with iron-ore beds, the typical Appalachian Clinton.

Clinton formation. The following members of the "Clinton" of the Second Pennsylvania Survey are actually of this age: (1) Clinton Lower lime shale and Clinton Upper olive shale (251 feet); (2) Fossil ore beds, ore sandstones, etc. (37.5); (3) Clinton Middle olive shale (178); (4) Iron sandstones (6.5); (5) Clinton Lower olive shale (571), which is sparingly fossiliferous.

Actual contact of the Clinton with the Medina not clearly exposed, due to talus, but it appears that there is a narrow transition zone. Between 100 and 200 feet above the Medina occur *Chonetes cornutus* (rare), *Leptocœlia hemispherica*, *Tentaculites minutus*, *Beyrichia lata*, *Calymene clintoni* (rare). Ever present in the Lower Clinton are the small ramifying branches of *Buthotrephis gracilis* Hall, which often can be used in a general way to locate the Lower Clinton. In the "Clinton Middle olive shale," in bed 54 of Dewees' section, there is an abundance of *Leptæna rhomboidalis*, *Chonetes cornutus*, *Camarotœchia*, and *Calymene clintoni*. In the "fossil ore beds" occur *Dalmanella elegantula*, *Chonetes cornutus*, *Leptæna rhomboidalis*, *Camarotœchia neglecta*, and *Atrypa reticularis*.

Silurian.

Medina or Tuscarora quartzites. Total thickness of "White Medina" 820 feet. A series of very hard, fine-grained, white, and cleanly washed quartzites in thick strata below and thinner bedded above, decidedly cross-bedded and without conglomerate. Toward the top more and more of thin sandy shales is interbedded, and between 200 and 300 feet above the base there is a zone, 50 feet thick, of a pinkish color. The white quartzites are much spotted with ferruginous specks, the result of oxidized siderite grains. At about 300 feet above the base of the formation *Arthrophycus alleghaniense* is very common, and apparently the same burrows were seen at 20 feet above the base. At many levels may also be seen the vertical burrows of *Scolithus verticalis*, and this fossil hereabouts is a more usual guide to the Medina than is *Arthrophycus*.

The contact with the Ordovician is a disconformable one and may be seen on the north side of the stream just where the trolley line begins to cross it. On the upper side of the break are white quartzites, somewhat darker than those higher in the formation, and these rest in marked contrast on the red quartzites of the Ordovician which have interbedded shale zones of a maroon color.

In the "Narrows" of the Juniata River, 3 to 5 miles southeast of Lewistown, the Upper Tuscarora sandstone is well displayed, but mainly as talus. Here it is a thin-bedded, gray to milky white and locally pinkish, cleanly washed, cross-bedded, fine-grained quartzite, interbedded with thin layers of greenish shale and an occasional thick one of black shale. *Arthrophycus alleghaniense* is common here, especially at the very top; the original locality for this guide fossil to the Medina is 10 miles east of Lewistown, on the Juniata River.

Probable break in sedimentation.

Ordovician.

Juniata formation. 1,590 feet thick. The upper member, "Medina Red Sandstone and Shale" of Dewees, is 1,280 feet thick. This soft formation, probably of continental origin, erodes into valley form and consists of brick-red, more or less cross-bedded, sandy shales, interbedded with muddy sandstones that become finer grained upward. The sandstones are replete with intraformational flat pebbles of red shale. There is also much rippling and sun-cracking. The uppermost 30 feet are much harder and cleaner red quartzites with thin separation zones of maroon colored shales. No fossils of any kind are present, and because of its stratigraphic position the formation is correlated with the similar Queenston of western New York, the continental phase of the marine Richmondian.

"Oneida Red conglomerate" of Dewees. Thickness, 310 feet. This is a mountain-making formation and forms the western ridge of Jacks Mountain. It consists of a series of heavy-bedded, coarse and conglomeratic, reddish quartzites, the material of a quick-running river laid down on the floodplain of a delta, since the cross-bedding and channeling are most marked. The formation is replete with zones of

conglomerate of vein quartz, quartzite, schist, and serpentine, in the main from the Precambrian strata to the eastward and in part from the sandstones of the Bald Eagle below. There are no limestone pebbles present. This conglomerate formation may also be of early Richmondian age.

Lorraine or Bald Eagle formation. Total thickness, 1,250 feet. Includes the "Oneida Gray sandstone" and Hudson River sandstones and shales of Dewees. At the bottom the marine "Hudson River" begins with dark greenish shales, that terminate in the upper 50 feet in thin strata of blue ferruginous arenaceous limestones (182 feet thick). In these limestones occur columnals of "*Heterocrinus heterodactylus*" Hall, Trepostomata Bryozoa, *Plectambonites sericeus*, *Rafinesquina alternata*, *Dalmanella meeki*, *Orthorhyncula linneyi*, *Zygospira modesta*, *Modiolopsis*, *Whiteavesia*, *Byssonychia radiata* (small here), and *Sinuites bilobatus*. These sandy shales pass into light greenish, fine-grained sandstones and shales (330 feet) that are probably still of marine origin, though they appear to be devoid of fossils, and then into coarser-grained flaggy sandstones with fewer and fewer shale partings (425 feet). Without break these are continued into the "Oneida Gray" quartzites (313 feet), which become more and more gray in color and conglomeratic (of well-rounded vein quartz pebbles less than half an inch in diameter), cross-bedded and apparently wholly of fluviatile origin, and pass unbroken into the Bald Eagle formation that is wholly of continental origin. The section continues downward unbroken into the still older Martinsburg formation.

Tyrone Gap, Bald Eagle Mountain, Pennsylvania.—Twenty-five miles west of Jacks Mountain. Based on a personal visit in June, 1916, and F. Platt: Second Geological Survey of Pennsylvania, Report T, 1881, pages 16-18; Lesley: Final Report, volume I, 1892, 657-659; Grabau: Bulletin of the Geological Society of America, volume 24, 1913, page 435.

Devonian.

Oriskany sandstone, about 50 feet. Coarse-grained sandstone in part conglomeratic. Not well exposed in this region. Best seen 27 miles northeast at Milesburg.

Milesburg formation, or Lower Oriskany, about 130 feet. Thin-bedded siliceous limestones, dark blue to black in color, terminating below in black siliceous shales. The equivalent of the Shriver formation of Maryland.

Great break. All of Upper Helderbergian absent.

Devonian. Helderbergian series.

Keyser formation, or Lower Helderbergian, about 115 feet. To be seen in northern and northwestern parts of Tyrone City. At the base is the cystid member, and toward the top occur two main zones of *Stromatopora* reefs.

Possible hiatus at this level.

Silurian. Cayugan series, about 1,350 feet (Rogers). The upper 700 feet are made up of more or less of light bluish ribbon limestones (= waterlime) that are often much mud-cracked, and the remainder consists of greenish shales interbedded with an occasional limestone (300 feet), followed by variegated marls and red shales (350 feet).

Great break. Most of Niagaran series absent.

Silurian. Niagaran series.

Clinton formation, about 1,000 feet (Rogers). The upper 46 feet consists of five thin zones of limestones in greenish shales, then 65 feet of red and greenish shales, then 50 feet having the flaxseed iron-ore beds, while most of the remainder of the section is concealed.

Silurian. Medina series.

Tuscarora sandstone, estimated at 500 feet, the thickness measured 27 miles to the northeast in the Milesburg Gap. A series of white, gray, and pink sandstones with thin shale partings.

Ordovician.

Break in section.

Juniata formation of the Richmondian, about 1,090 feet. Can be seen in Juniata Gap along wagon road east of Tyrone City. The detailed sequence is described by Platt on pages 17-18 of the cited report. It is a series of dominantly reddish, cross-bedded, hard and soft, muddy sandstones interbedded with thin zones of a sandy shale. There are occasional thin zones of a greenish color, and many mud-cracked layers with some of the cracks nearly a foot deep. The lower 250 feet are coarser-grained sandstones.

Bald Eagle sandstones, apparently 1,320 feet thick. Thin-bedded light greenish sandstones interbedded with green sandy shales and an occasional red shale zone, the whole becoming more and more thin-bedded and shaly downward, passing into the

Martinsburg dark shales, about 900 feet.

Cumberland-Keyser region, Maryland-West Virginia.—Along the Potomac River, 75 miles south of Tyrone. See Schuchert: Proceedings of the U. S. National Museum, volume 26, 1903, pages 413-424, and Maryland Geological Survey, Lower Devonian volume, 1913.

Devonian.

Upper Oriskany or Ridgley sandstone, about 260 feet.
Lower Oriskany or Shriver chert, about 90 feet.

Break. All of higher Helderbergian absent.

Devonian. Helderbergian series.

New Scotland member, about 60 feet.
Keyser member, from 270 to 300 feet.

Probable break.

Silurian. Cayugan series.

Tonoloway member, about 630 feet.
Wills Creek member, about 663 feet.

Great break. Most of Niagaran absent.

Silurian. Niagaran series.
  Clinton formation, about 600 feet.

Silurian. Medina series.
  Tuscarora sandstone, about 290 feet.

Probable break.

Ordovician. Richmondian series.
  Juniata red sandstone, 530 feet seen. Probable thickness not less than 730 feet.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

COMPARISON OF AMERICAN AND EUROPEAN LOWER ORDOVICIC FORMATIONS[1]

BY AMADEUS W. GRABAU

(Presented before the Paleontological Society December 30, 1915)

CONTENTS

[1] Manuscript received by the Secretary of the Geological Society August 25, 1916.
This is the first of a series of comparative studies of the European and American Paleozoic, based on investigations and collections made by the writer during eight months' sojourn in northern Europe in 1910.

Introduction

Geologists familiar with the formations of both hemispheres will in general agree that while Europe must always serve as the type region for the Mesozoic and Cenozoic formations, the North American Paleozoic should be considered the standard by which other deposits of that age must be judged. In no other known region is there such an extensive development of the older formations, both in their marine and continental phases, and in no other known portion of the world is the record so clearly preserved as in the Paleozoic rocks of the greater part of the North American continent. This is especially true of the earlier systems, which have not only a slight representation over much of Europe, but are for the most part strongly disturbed; or, where not so affected, as in the Russian region, are in large part covered by comparatively recent surface deposits. This is emphasized by the extent of the treatment accorded the several divisions of the column in the standard European treatises. Thus, Kayser in his "Lehrbuch der Geologischen Formationskunde," fourth edition, devotes 273 pages to the Paleozoic and 400 pages to the remainder of the column, above the Paleozoic, the Paleozoic thus receiving about 40 per cent of the whole. Of the 273 pages given to the Paleozoic, 30 are devoted to the Cambric, 55 to the Ordovicic and Siluric, 60 to the Devonic, 66 to the Carbonic (including the Mississippic), and 61 to the Permic. Of the 217 pages devoted to the Mesozoic, 81 go to the Triassic, 60 to the Jurassic, and 76 to the Cretacic, including the Comanchic of American usage. Haug in his "Traité de Géologie" gives 34 pages to the Cambric, 50 to the Ordovicic and Siluric, 71 to the Devonic, 105 to the Anthracolithic (Mississippic-Permic), or a total of 260 pages to the Paleozoic. To the Triassic he gives 81, to the Jurassic 224, and to the Cretacic (inclusive of Comanchic) 244, making a total of 549 to the Mesozoic, or more than double that given to the Paleozoic. The Tertiary (Cenozoic) is discussed in 363 pages and the Quaternary (Psychozoic) in 162 pages. The Paleozoic thus receives 19.5 per cent, or about one-fifth of the space devoted to the entire post-Algonkic history of the earth.

In the large volume on the Paleozoic of the world, in the Lethæa Geognostica, Frech devotes 45 pages to the Cambric, 56 to the Ordovicic-Siluric, 140 to the Devonic, and 408 pages to the remainder of the Paleozoic. The Triassic is treated in a separate volume of 561 pages, while the higher formations promise to be treated with similar generosity.

If we now look at the volumes of Chamberlin and Salisbury, where the American standpoint is taken, we find that the Paleozoic has devoted to it 460 pages, of which 86 go to the Cambric, 64 to the Ordovicic, 50 to the Siluric, 78 to the Devonic, 43 to the Mississippic, 80 to the Pennsylvanic, and 59 to the Permic. The Triassic is considered in 58 pages, the Jurassic in 47 pages, the Comanchic in 31 pages, and the Cretacic proper in 54 pages, making a total of 190 for the Mesozoic. The Tertiary receives 136 pages and the Quaternary 216 pages; thus the Paleozoic comprises nearly 46 per cent of the entire treatise on post-Algonkic systems.

In the fourth edition of Dana's "Manual" 278 pages are devoted to the Paleozoic, 141 to the Mesozoic, and 158 to the Tertiary and Quaternary, the Paleozoic receiving thus 49 per cent, or nearly one-half, of the space given to the entire post-Archean portion of the section on Historical Geology. If the various treatises were strictly devoted each to its own country, the discrepancies would be even more marked than they are.

In the succeeding pages of this paper some of the Lower Paleozoic formations of Europe are considered in the light of the knowledge gained by a study of American formations of the same age. My field studies in Europe were made during the last eight months of the year 1910, and the material then collected has been studied at intervals since that time in the laboratory. While considering the lithologic and faunal characters of the several formations, emphasis will also be laid on the evidences for the occurrences in the European field of the disconformities and hiatuses known to separate certain American formations, and which may owe their existence to diastrophic movements.

Lower Ordovicic of Europe and North America compared

The classification of the Ordovicic rocks of western Europe is generally based on the British succession, since that was the first to be determined and defined. As is well known, these rocks were called by Sedgwick Upper Cambrian, and by Murchison, Lyell, Phillips, and others, Lower Silurian. Even the *Lingula flags* and the *Menevian* were included by Jukes (1863) in the Lower Silurian or Cambro-Silurian, while Murchison (1868) called them "Primordial Silurian." The Geological Survey in

1865 likewise included them in the Lower Silurian, thus leaving only the Harlech grits to represent the Cambrian. Ramsay in 1878 went even further, including all the formations in the Silurian—a proceeding in which he was anticipated by Barrande[2] and followed by some recent writers, notably Bernard (1895). Lapworth's classification of 1879 has now become the standard for British as well as American geologists, though continental geologists still retain Silurian for the two upper divisions, referring to them either as Lower and Upper Silurian, Unter und Ober Silur (Kayser, etcetera), or as Ordovicic and Gotlandic (Haug and some Swedish geologists).[3]

The Tremadoc rocks of Wales were considered by Barrande as transition beds between those carrying the first (Cambric[4]) and those holding the second (Ordovicic) faunas. They were included in the Cambrian by Lapworth, and have there been generally retained by British geologists. On the continent of Europe, however, the rocks of this age are now being generally classed as Lower Ordovicic (tieferes Untersilur), and the dividing line is drawn at the base of the *Dictyonema flabelliforme* shales.

The British subdivisions of the Ordovicic, as now used, fall into the following five groups, in descending order:

5. Ashgillian or Upper Bala.
4. Caradocian or Middle Bala.
3. Llandeilan or Lower Bala.
2. Arenigian or Arenig.
1. Tremadocian or Tremadoc.

From the point of view of continuous sedimentation, these five groups may be combined into three divisions, separated from one another and from the succeeding and sometimes the preceding ones by disconformities (more rarely unconformities). These combinations are (*a*) the Tremadocian and Arenigian, (*b*) the Llandeilan and Caradocian, and (*c*) the Ashgillian. In a general way these correspond to (*a*) our Beekmantownian (including the Dictyonema beds, Potsdam, and Little Falls horizons), (*b*) our Chazyan and Trentonian (to the top of the Lorraine), and (*c*) our Richmondian. With us, too, these formations are separated

[2] See especially "Du Maintien de la Nomenclature établie par M. Murchison, par M. J. Barrande." Extrait du Compte Rendu Sténographique du Congrès International de Géologie, tenu a Paris du 29 au 31 août et du 2 au 4 Septembre, 1878.

[3] For a summary of the early history of classification see J. E. Marr: The classification of the Cambrian and Silurian rocks. Geological Magazine, decade ii, vol. viii, pp. 245-250. June, 1881.

[4] The terms *Cambric, Ordovicic,* and *Siluric* are used in the sense generally employed in this country, while Cambrian of Sedgwick refers to the series from the Harlech to the Bala, inclusive. Silurian has a different value according to the author employing it, from Barrande and Ramsay, who include the Cambric, Ordovicic, and Siluric in it, to Sedgwick and Lapworth, who use it in the sense of our Siluric only.

by widespread disconformities, and such breaks in sedimentation also succeed, and probably very generally precede, the series. That these breaks in the sedimentary record are due to extensive retreatal or negative eustatic movements of the sea seems unquestionable, and on this account it would appear that such breaks furnish valuable datum planes for delimiting definite divisions of the stratigraphic scale inclosed between them. It must, however, always be borne in mind that the retreat of the sea and its readvance occupied a considerable time interval, and that during such movements sedimentation continued longer and recommenced earlier in the region of later emergence during retreat, and of earlier submergence during readvance, of the sea—that is, in the region farthest removed from the shoreline at the beginning of the retreatal movement—than it did in this shoreline region. Concomitantly, the region of first emergence and last resubmergence would suffer most erosion. Again, it must not be forgotten that the borders of the emerging continents, as well as occasionally some sections within the continents, still remained submerged at the end of the retreatal movements, and that hence sedimentation there was entirely continuous. Those regions may in many cases be beyond the confines of the present dry-land masses, but in others they are undoubtedly within the present borders of these lands, though erosion during later periods may have removed the record. To use such disconformities as limiting planes for geological systems when unaccompanied by decided changes in faunas seems at present hardly warranted, though it must be conceded that if the exact limits of the retreatal and readvance movement could be determined, provided such movements were everywhere uniform or with but minor oscillations, and if more or less marked faunal changes could be proved to accompany such changes, a very satisfactory and convenient basis for subdivision of the geological column would be furnished. If such a basis could be adopted, the systems would include the deposits formed from the beginning of the transgressive movement to its culmination, and then to the end of the regressive movement. Each system would thus be separable into two divisions, one representing the transgressive and the other the regressive movement. Since such movements were, however, very probably not all of the same magnitude, our systems would be of unequal value; and while some might be sufficiently great to be accompanied by great faunal changes (more or less induced by these physical changes), others might show no such parallel effects in the organic world.

In the case of the formations now included in the Ordovicic, we would have three diastrophic systems—the Tremadoc-Arenig, the Llandeilo-Caradoc, and the Ashgillian. The last of these is the smallest in point

of sedimentation, so far as known, but is accompanied by the most pronounced faunal change, since it marks the appearance of faunal elements generally regarded as typical of the Siluric. The corresponding American systems would be the Beekmantownian (including the Ozarkian, in a modified sense, as the transgressive phase[5]), the Chazy-Trenton, and the Richmondian. As will be shown later, however, the pre-Richmond emergence was not comparable in magnitude to the emergence marking the end of Beekmantown time. Schuchert uses the terms Canadian, Champlainian, and Cincinnatian for these three diastrophic cycles; but in his Cincinnatian he includes what is most certainly a part of the emergence phase of his Champlainian cycle, namely, the Utica shale. The Chazy and Trenton were included by Dana in the first edition of his manual in the Trenton period, which is essentially equivalent to Schuchert's modified Champlainian (not the Champlainian of Clarke and Schuchert, 1899). The Utica and higher beds were placed by Dana in the Hudson period in 1863, but included with the Trenton limestone (inclusive of the Black River and "Birdseye") in the Trenton period in the fourth edition in 1895, when he placed the Chazy within the Canadian. It is in this sense that I here use the term Trentonian, a term essentially equivalent to the English Caradocian.

Lower Ordovicic of North Scotland and its Relation to similar Deposits Elsewhere

GENERAL PETROGRAPHIC AND FAUNAL CHARACTERISTICS

One of the remarkable features of the early Paleozoic rocks of Britain is the striking difference in character and faunas between the Cambric and Ordovicic rocks of the northern and of the southern area. The southern area, which comprises all the regions south of the Scottish Highlands, includes the type regions for the Cambric, Ordovicic, and Siluric formations, which are for the most part developed in their terrigenous facies as quartzites, graywackes, sandstones, and mudstones, while limestones are more rarely represented. The prevailing element of the entombed faunas is furnished by the graptolites, though trilobites are also of frequent occurrence. It is this southern or English fauna which has its close analogue in northeastern North America (New Brunswick, Cape Breton, eastern Newfoundland, eastern New England, etcetera), and the faunas found in these beds must be regarded as representing that of the somewhat expanded Atlantic of that time.

[5] This is the Potsdam period of the first edition of Dana's "Manual" (1863), which he divided into, 1, *Potsdam epoch*, and 2, *Calciferous epoch.*

The northern development, found in the northwest of Scotland, is totally different from the southern, for mudstones are rare or lacking, and the lithic development comprises sandstones and limestones or dolomites. The faunas are wholly distinct from those of the southern area, this distinction being expressed not only in specific, but far more pronouncedly in generic, differences.

THE NORTHERN SECTIONS

I have studied these formations at various localities in the northwest of Scotland, especially in the vicinity of Durness, and along the rugged shores of Loch Eriboll. The series begins with a great quartzite, generally of pure quartz grains, though the lower part contains much feldspar, while the base consists of a thin conglomerate of coarse and fine fragments. The rock rests either on the old Lewisian gneiss, from the disintegration and decomposition of which the quartzite has been derived, or on an intervening sandstone and conglomerate, the Torridonian, which itself is an earlier, terrestrial derivative from the gneiss.

The total thickness of the basal, sandy, or quartzite series is almost 600 feet. The lower third is cross-bedded and feldspathic, and without fossils, representing a purely terrestrial accumulation. The upper two-thirds is more or less fossiliferous and may represent, in part at least, a seashore accumulation. It abounds in vertical worm-holes, mostly of the types referable to Scolithus, from which a part of the rock received its name of "pipe-rock." The upper part becomes more calcareous, and Salterella, Hyolithes, and Olenellus make their appearance. This portion represents the Lower Cambric division, the fauna being of the Pacific type and like that of the Appalachian trough of North America. The entire series is generally spoken of as the *Eriboll quartzite series,* from its excellent development on the shores of Loch Eriboll. Through the calcareous zones the series grade upward into a pure dolomitic limestone, which goes under the name of the *Durness limestone series,* from the fine exposures found in the vicinity of that village in northwestern Scotland. The lower part of this calcareous series is conformable with the underlying sandstones, with which it forms a continuous depositional unit. The total thickness of this calcareous series is almost 1,500 feet, and it is divisible into the several following groups:

Durness limestone series, 1,500 feet:

VII. Durine group.
VI. Croisaphuill group.
V. Balnakiel group.
IV. Sangomore group.

III. Sailmhor group.
II. Eilean Dubh group.
I. Ghrudaidh group.

Eriboll quartzite series:

	Feet
Serpulite grit	30
Fucoid shales	40–50
Pipe-rock	300
Basal sandstone and conglomerate	200

Unconformity.

Lewisian gneiss or Torridonian sandstone.

The Fucoid shales carry a considerable Lower Cambric fauna, including four species and two varieties of Olenellus, as well as such characteristic species as *Kutorgina* (*Iphidea*) *labradorica* Bill. and others found in the American Lower Cambric of the Appalachian province. The Serpulite grit contains *Salterella maccullochi* (Salter) and *Olenellus lapworthi*. The succeeding Ghrudaith limestone contains three species of Salterella—*S. maccullochi* (Salt), *S. pulchella* Bill., and *S. rugosa* Bill.—the last two being American species. The Salterella are distributed in two bands in the Ghrudaith limestone, one at the base and one almost 30 feet above it. The upper part is mottled dolomite, "the mottling being due to the great abundance of worm-casts of the nature of Planolites."[6]

The Eilean Dubh group of fine-grained, white, flaggy limestones is destitute of fossils, except those markings which have been referred to worm-casts. This appears to have been a shallow-water accumulation with occasional hardening of the layers on exposure and the production of intra-formational breccias. An examination of the beds of this group on Eilean Dubh (The Black Isle), in Balnakiel Bay, near Durness, which I was able to make in 1910, disclosed such a zone about 10 feet thick on the eastern side of the island, continuing with irregular thickness and showing no stratification. The rock is a calcilutite and is succeeded irregularly by a fine calcarenite.

On the west side of the island, just above high-water mark, is an interbedded conglomerate, with worn pebbles of limestone generally less than an inch in diameter, the bed varying in thickness from a few inches to a foot. There is also a green clay streaking the conglomerate in places. The rock above this clay layer likewise appears conglomeratic or brecciated; but this structure is not very distinct, and since the pebbles and matrix are essentially of the same material, it is often difficult to differ-

[6] B. Peach and J. Horne: The geological structure of the northwest highlands of Scotland. Great Britain, 1907.

entiate them. In one place this overlying, pebbly mass is 1 foot and 8 inches thick. The brecciated zone above referred to follows immediately above this conglomerate, thus showing the whole to be a zone of prolonged disturbance. The surface on which the conglomerate rests is on the whole very level, though minor irregularities are noticeable. The following sketch, reproduced from my notebook, shows some of these.

This contact can be traced across the low neck (submerged at high tide) which connects the island with the mainland, its position being at or just below high tide, and the exposure being essentially along the strike of the beds, and thus appearing horizontal. On the mainland it can be traced in the cliff for some distance along the shore of the Kyle of Durness.

The significance of this conglomerate lies in the fact that it marks a period of distinct emergence, followed by erosion and resubmergence of

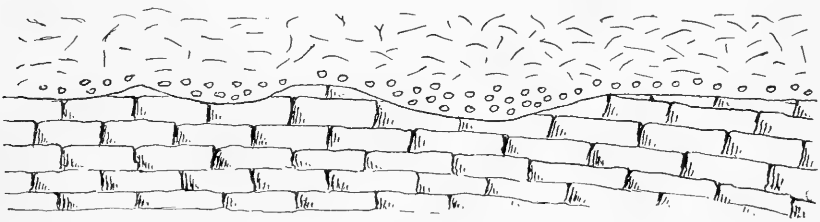

FIGURE 1.—*Disconformable Contact of Lower Ordovicic on Lower Cambric at Eilean Dubh, near Durness, Scotland*

the region. The magnitude of the hiatus here represented is, however, not apparent; from the physical appearances one would be tempted to assign little significance to it. The fact, however, that the beds some distance above carry a typical Lower Ordovicic (Beekmantown) fauna makes it evident that its significance is greater than would at first appear, for the entire Middle and Upper Cambric is here cut out, indicating a period of prolonged exposure and of non-deposition of the later Cambric strata.

It may be added that the physical evidence of a hiatus known to exist in other cases is no more marked than that found here. Such is the case in the Siluro-Devonic contact in sections of western New York, Canada, and Michigan, where the whole Lower Devonic is wanting, as well as a part of the Upper Siluric.

It is possible that this conglomerate marks only a minor emergence, and that the great break between the Lower Cambric and the Lower Ordovicic is somewhat higher. The beds which succeed the conglomerate layer are at first massive, fine, calcarenites, followed by thin-bedded calcilutites, which on weathered surfaces show a fine cross-bedding, such as would be produced by migrating ripples. This is sometimes very marked,

but is always on a small scale. Higher still occur massive beds which show little bedding, but are characterized by a vertical flaking. At the top of this are the brecciated layers.

About 125 feet above the conglomerate, at the top of the first cliff, back of the shore cliff, is an exceedingly irregular line of contact between dolomitic calcarenites and the overlying calcilutites. The following sketch from my notes shows this contact as exposed on a part of the cliff.

It is difficult to decide whether this is a sedimentary contact or represents irregularity of dolomitization of the limestones. The appearance in some cases suggests irregular ridges of dolomite, comparable to the "yardangs" of central Asia, as described by Sven Hedin.[7] The spaces

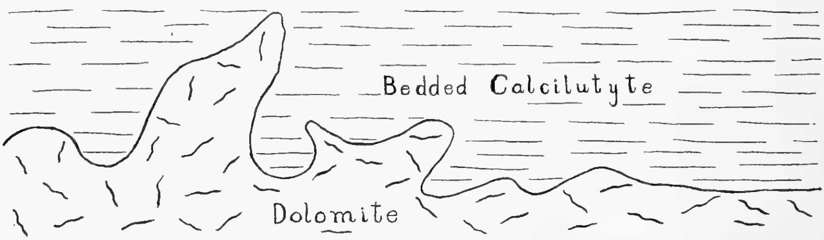

FIGURE 2.—*Irregular Contact between Dolomite and bedded Calcilutite in the Cliffs facing the Kyle of Durness, Scotland*

This may represent the Cambro-Ordovicic disconformity

between the ridges are filled with fine, stratified lime mud. This often shows brecciation, and fragments of dolomite are frequently included in the limestone, resembling broken-off masses.

Somewhat higher begin the beds of the Sailmhor group, which comprise for the most part strongly mottled dolomites, to which the local name, *leopard stone*, is applied. The rock has the appearance of a breccia composed of dark and light angular fragments. The brecciation is probably the result of dolomitization. Much chert is present, but the rock as a whole shows little evidence of stratification. This rock has furnished the following fossils:[8]

1. *Isotelites canalis* (?) Conrad.
2. Murchisonia sp.
3. *Pleurotomaria* (Euconia) *etna* Bill.
4. *P.* (Euconia) *ramsayi* Bill.
5. Cyrtoceras, two species.
6. Orthoceras sp.

[7] See illustration reproduced in my Principles of Stratigraphy, p. 53, fig. 13.
[8] Peach and Horne: Loc. cit., p. 629.

Of these, numbers 1 and 3 have been obtained from the Beekmantown of Newfoundland (1 from zones F-M and 3 from zones G-H of Billings), while number 4 was originally described from the Lower Beekmantown (Romaine) of the Mingan Islands.

It is thus evident that the lowest fossiliferous beds succeeding the indicated break in the series have a typical Beekmantown fauna, and although these and the succeeding members of the Durness limestone series are classed as Middle and Upper Cambric by British geologists, it is clear that they belong in the base of the Ordovicic, and that Middle and Upper Cambric are wanting here. The conditions are thus the same as those found in western Newfoundland and in the Saint Lawrence Valley, as well as in the region east of Lake Champlain, where Lower Ordovicic beds follow on Lower Cambric. Moreover, it is evident that the faunal characteristics of the Durness series ally it with the Beekmantown limestones of western Newfoundland rather than with those of any other British or continental formation. The close correspondence between the North Scottish and American deposits, expressed even more strongly in the succeeding members of the Durness group, was pointed out as early as 1859 by Salter, and has been recognized by every one since. Yet these beds have always been referred to the Cambric by British geologists, even though some of the fossils found in the higher beds are of Black River types.

No fossils have been found in the Sangomore dolomites, but the Balnakiel and Croisaphuill groups contain a considerable assemblage of organisms, all of which I had the opportunity of studying in the collections of the Edinburgh Museum through the courtesy of the custodians. The specifically identified forms are given in the following:

TABLE OF ORDOVICIC SPECIES FROM THE DURNESS LIMESTONE

(Modified from Peach and Horne)

	Balnakiel group.	Croisaphuill group.	Durine.	Skye.	American occurrence.
SPONGIDA, etcetera:					
1. *Archæoscyphia minganensis* (Bill.)	×	×	....	×	Beekmantown (Romaine), Mingan Islands.
2. *Calathium anstedti* Bill.	×	....	....	×	Zone H, Newfoundland.
3. *Calathium ? pannosum* Bill.	....	....	....	×	Point Levis, Quebec.
4. *Receptaculites calciferus* Bill.	....	....	....	×	Beekmantown (Romaine), Mingan Islands.
5. *Receptaculites elegantulus* Bill.	....	....	....	×	Beekmantown (Romaine), Mingan Islands.
TRILOBITA:					
6. *Bathyurus (Petigurus) nero* Bill.	....	×	....	....	Zones F, G, H, and N of Billings, Newfoundland.
7. *Conocoryphe chippewaensis* Owen.	×	×	....	....	Lower Cambric, New York.
BRACHIOPODA:					
9. *Camerella (Swantonia) antiquata* Bill.?	×	×	....	....	Lower Cambric, Vermont.
10. *Orthisina (Nisusia) festinata* Bill.?	....	×	....	×	Lower Cambric, Vermont, New York, Labrador, etc.
11. *Billingsella ? grandæva* (?) Bill.	....	....	....	×	Beekmantown (Romaine), Mingan Islands.
12. *Orthis striatula* Salter	×	....	....	×	
PELECYPODA:					
13. *Euchasma blumenbachi* Bill.	×	×	....	×	Zones G and H, Newfoundland.
and varieties	×	×	....	×	(Also Mingan Islands.)
GASTROPODA:					
14. *Bellerophon (Oxydiscus) palinurus?* Bill.	....	×	....	....	Beekmantown, Canada East.
15. *Holopea leiosoma* Bill.	....	×	....	....	Number 3 limestone, Point Levis, Quebec.
16. *H. ophelia* Bill.	×	....	....	×	Zone L, Newfoundland.

17. *Maclurea acuminata* Bill	....	....	....	×	Zones K-M, Newfoundland.
18. *Maclurea crenulata* Bill	×	×	....	×	Zones J, K, L, and M, Newfoundland.
19. *M. emmonsi* Bill	....	....	....	×	Zones J, K, L, and M, Newfoundland.
20. *M. oceana* Bill	×	×	....	×	Zones F, G, H, Newfoundland, Beekmantown.
21. *M. peachi* Salter	×	×	....	×	
other species	×	×	....	×	Newfoundland.
22. *Murchisonia (Ectomaria) adelina* Bill.	×	×	....	×	Zone G, Beekmantown, Newfoundland.
23. *M.* (*Hormotoma*) *anna* Bill	×	×	....	×	Beekmantown, Mingan Islands.
24. *M.* (*Hormotoma*) *antiqua* Donald	....	×	....	....	
25. *M.* (*Hormotoma*) *artemesia* Bill	×	×	....	×	Beekmantown, Canada, Virginia.
26. *M.* (*Lophospira*) *augustina?* Bill	×	....	....	×	Zones H-N, Newfoundland, Trenton, Minnesota.
27. *M.* (*Hormotoma*) *bellicincta* Hall	×	....	....	×	Trenton, New York, Minnesota.
28. *M.* (*Lophospira*) *borealis* Donald	×	×	....	×	Trenton, Alumette Island, Canada.
29. *M.* (*Hormotoma*) *gracilis* Hall	×	×	×	×	Black River to Richmond, United States, and Canada.
30. *M.* (*Hormotoma*) *gracillima* Salt	×	×	×	×	
31. *Murchisonia* (*Cœlocaulus*) *linearis* Bill.	×	×	....	....	Beekmantown, Mingan Islands.
32. *M.* (*Ectomaria*) *pagoda* Salt	×	....	....	×	Black River, Ottawa, Canada; New York, Minnesota, Wisconsin.
33. *M.* (*E.*) *pagoda* var. *orientalis* Donald.	....	×	....	×	
34. *M.* (*E.*) *pagoda* var. *peachi* Donald	×	×	....	×	
35. *Ophileta compacta* Salt	×	×	....	×	Beekmantown of Quebec.
36. *O. complanata* Vanux	....	....	....	×	Beekmantown, New York, Vermont, Pennsylvania, Maryland, Virginia, etcetera.
37. *O. nerine* Bill	....	....	....	×	Zone F, Newfoundland.
38. *Pleurotomaria* (*Trochonema*)? *calphurnia* Bill.	×	×	....	×	Newfoundland.
39. *Pleurotomaria* var. 1	×	×	....	×	
39*a*. *Pleurotomaria* var. 2	×	×	....	×	
40. *Pl. arabella?* Bill	×	....	....	....	Beekmantown, Canada.
41. *Pl.* (*Euconia*) *beekmanensis?* Whitf.	×	×	....	×	Beekmantown, New York.
42. *Pl. calcifera* Bill	×	×	....	×	Beekmantown, Canada.
43. *Pl. canadensis* Bill	×	....	....	....	Beekmantown, Canada, Mingan Islands.
44. *Pl.* (*Ectomaria*) *dryope* Bill	×	....	....	....	Black River, Ottawa; Minnesota, Missouri, Tennessee.

	Balna-kiel group.	Croisa-phuill group.	Durine.	Skye.	American occurrence.
45. *Pl.* (*Euconia*) *etna* Bill.	....	×	....	....	Zones G, H, Newfoundland.
46. *Pl. gregaria* Bill.	×	×	....	....	Beekmantown, Canada; Mingan Islands.
47. *Pl.* (*Raphistomina*) *laurentina* Bill.	....	×	....	×	Beekmantown (Romaine), Mingan Islands.
48. *Pl.* (*Euconia*) *ramsayi* Bill.	....	×	....	×	Beekmantown (Romaine), Mingan Islands.
49. *Pl.* (*Helicotoma*) *spinosa* (Salt.)	×	×	....	....	Black River, Ottawa River, Canada.
50. *Pl. thule* Salt.	×	....	....	....	
51. *Pl.* (*Sinuopea*) *turgida* Hall	....	×	....	×	Little Falls dolomite, New York; Beekmantown, Iowa.
CEPHALOPODA:					
52. *Orthoceras arcuoliratum* Hall	×	....	....	....	Trenton, New York.
53. *O. vaculoides* Blake	×	....	....	×	
54. *O. durinum* Blake	×	....	....	×	
55. *O.* (*Actinoceras*) *mendax* Salt.	×	×	....	×	Newfoundland? Mingan Islands?
56. *O.? pertinens* Blake	×	×	....	×	
57. *O.? undulostriatum* Hall	×	×	....	....	Trenton, New York.
58. *Cycloceras olorus* (Hall)	×	×	....	....	Black River, Wisconsin, Minnesota; Trenton, New York; Minnesota.
59. *Pilocerus invaginatum* Salt.	×	×	....	×	Beekmantown, Newfoundland; Fort Cassin.
60. Trocholites, 4 species.					
INCERTÆ SEDES:					
61. Planolites	×	×	....	×	Beekmantown.

DISCUSSION

Of these 60 species, 3 (numbers 7, 9, and 10) are reported from the Lower Cambric. These include one trilobite, doubtfully identified, and two brachiopods. The trilobite was not to be found in the Edinburgh collection; the brachiopod identified as *Camarella* (*Swantonia*) *antiquata* Bill. is a small inner mold, with characters inconclusive. Walcott does not cite it from the Durness limestone in his revision of that species. The same is true of *Orthisina* (*Nisusia*) *festinata* Bill. Of the identified species, 29, or 47.5 per cent, occur in the Beekmantown of eastern Canada or New York; 5, or about 8.5 per cent, occur in beds referred to the Chazy in Newfoundland, but which may also belong to the Beekmantown; 5, or about 8.5 per cent, are found in the Black River beds of America, and 4, or about 6.5 per cent, in the Trenton and higher beds of the American Ordovicic.

In spite of the 25 per cent of species identified with Chazy or younger American forms, the fauna is probably a unit, for the material identified is as often as not from the lower of these beds. It is not impossible, however, that the higher part of the Croisaphuill group may include a Chazyan horizon, there being in that case a hiatus between the Chazyan and the Beekmantown portion of this group. The only fossils listed from the Durine group are *Hormotoma gracilis,* a typical American Black River to Richmond species, and *H. gracilima* Salter. This series may represent Black River or younger Ordovicic horizons of the East American type. It should, however, be remembered that the preservation of these forms is generally such as to render absolute identification difficult, if not impossible.

As has been stated, the Scottish series finds its counterpart in the deposits of western Newfoundland, as shown at Bonne Bay, Table Head, and Cowhead. The lower part of this series, including divisions A-C, with a total of 2,020 feet, represents the Lower Cambric and carries the Olenellus fauna. This part is therefore the analogue of the Eriboll quartzites and the Serpula grits of northern Scotland. Divisions D to H, inclusive, with a thickness of 1,839 feet, represent the Beekmantown. The contact between D and C is shown in Bonne Bay, but its detail has not been worked out. From 250 to 300 feet below the top of Division C, as defined by Logan and Billings, occurs a white quartzite in beds of from 2 to 3 feet thick and interstratified with pyritiferous magnesian limestones, which constitute one-fourth of the mass. This quartzite may mark the actual contact and conceal the hiatus between the Lower Cambric and the Lower Ordovicic strata. The beds below this sandstone are shales and limestones carrying the Olenellus fauna, while those above are

mostly calcareous, the Beekmantown fauna appearing some 400 feet above the top of the quartzite.

The highest member of the Newfoundland series, which is commonly included in the Beekmantown, is Division H, seen at Table Head, where 100 feet of limestone with *Orthis electra ?, Maclurea matutina ?,* and *Orthoceras piscator* are shown. The next 165 feet are concealed, and here falls the contact with divisions I to M, which are placed in the Upper Chazyan and Black River. From the fact, however, that the typical Beekmantown species *Maclurea matutina* and *Dalmanella electra* are also found in I and K, it is suggested that these two divisions also belong to the Beekmantown. Logan, however, says (1863 Report, page 871): ". . . The chief part of the species of the remaining gastropods and cephalopods [of divisions K, L, and part 1 of M] are so closely allied to some of the common forms of the Trenton group that it scarcely appears doubtful that they are the same. The most striking resemblances are to *Orthoceras bigsbyi* and *O. allumettense* of the Birdseye and Black River, and to *Murchisonia gracilis, M. bellicincta,* and *M. perangulata* of the Trenton formation." If one places the dividing line with Ulrich and Bassler, between divisions I and H, it probably falls in the covered interval. The upper beds of M contain *Camarotœchia plena,* the zone fossil of the Upper Chazy of Lake Champlain, together with *Camarella varians,* another typical Upper Chazy species. The same species are found in the lower part of N, which succeeds it; but the remainder of N, as well as divisions O and P, are, in part at least, a repetition of the series, including probably both the lower and the upper succession. If we include the series from D to the middle of Division M in the Beekmantown, we have a total of 2,615 feet for this formation and at least 560 feet for the succeeding Chazy. Judged by these standards, the North Scottish species listed under numbers 16, 17, 18, 19, and 26, and referred to the Chazy, would still be referable to the Beekmantown, thus increasing the Beekmantown species to 34, or about 56.5 per cent, while the Black River-Trenton forms comprise only 9 species, or 15 per cent. These, if correctly identified, would then have to be considered long-lived species.

Biri Limestone of Norway

In the Mjösenseė district of Norway the strata which have been found resting on the crystalline basement complex have been divided as follows, in descending order, according to Goldschmidt.[9]

[9] Münster: Norg. Geol. Und. Aarbog for 1891 and Blatt Lillehammer, 1900. Goldschmidt: Ibid., 1908, vol. ii, p. 38.

Olenellus shale.
Upper Algonkian.
  Sandstone with tracks and trails.
  Quartz sandstone.
  Red and green shale.
  Younger sparagmite.
Middle Algonkian.
  Biri limestone.
Lower Algonkian
  Biri conglomerate.
  Red shale and limestone.
  Older sparagmite with dark shales.
Crystalline basement.

Between the Biri limestone and the succeeding beds there was postulated a marked hiatus, the higher beds resting unconformably on the folded and eroded Biri limestone and older beds.

In 1910 Prof. A. Rothpletz made a detailed study of these beds in the Mjösen region and came to the conclusion that the "Upper Algonkian series" represents merely the overthrust portion of the lower Sparagmite series which grades laterally into sands and quartzites. The series thus resolves itself into a basal sandstone, which merges laterally into Sparagmite and is followed by the Biri limestone. Such overthrusts from the north or northwest are frequent in the Scandinavian region, bringing sometimes the older sediments as well as the crystallines to rest on the Ordovicic and Siluric. Törnebohm has determined that the entire mass involved in the strata of the Mjösen district has been shoved some 130 kilometers or more eastward and southeastward from its original locality.

The Sparagmite comprises a mixture of arkoses with fresh feldspar crystals, and breccias formed of irregular fragments of crystalline rocks mostly with ill-defined stratification, but interbedded with well stratified sands and clays. Walther[10] has compared it with the Torridon sandstone of Scotland and considers both of torrential origin formed under the control of a semi-arid climate. The rock is the product of disintegration of the old basement crystallines and of the recomposition of this material into the Sparagmite, with but a small amount of sorting of the fragments. This basal Sparagmite and sandstone Rothpletz regards as, in part at least, early Cambric, though it may go back to pre-Cambric time. The Biri limestone, which succeeds it, is also considered by Rothpletz as of

[10] Über Algonkische Sedimente, von Johannes Walther. Zeitschrift d. deutschen geologischen Gesellschaft, Bd. 61, 1908, pp. 283-305.

Cambric rather than Algonkian age. No fossils have been found in this rock so far, so that its age is problematical. But if Rothpletz has solved the tectonics of the region correctly, it is most certainly Lower Paleozoic. The Biri limestone is a mixture of calcilutites and calcarenites; it is generally well stratified, and edgewise conglomerates, intraformational folding through slumping, as well as sun-cracks, appear in it, indicating relatively shallow water conditions during accumulation, with intermittent emergences. Ripple-marks were also observed by Walther on some of the surfaces.

The development of early Paleozoic rocks in a calcareous facies like that of the Biri limestone in the northwestern part of the Scandinavian land-mass, whence these thrust masses are derived, is the more remarkable, since the sandy and shaly development of these strata in the southern part of the peninsula and even in the region in which these limestones are now found shows a distinctly northward overlap, a condition of occurrence which presupposes the existence of a land-mass in the neighborhood. This land-mass must have lain between the area of the marine transgression from the south and the region of deposition of the Biri limestone. This limestone might be regarded as deposited in a great area of inland waters, but, as Walther rightly remarks, its extent and the absence of silicious clastics in it form a difficult problem on the basis of such an assumption. To be sure, the maximum thickness today is only 170 to 200 meters, but that is not its greatest original thickness, for its relation to the higher beds is in nowise definitely ascertained.

A more rational explanation of the origin of this limestone would seem to be that its accumulation took place in the waters of a sea lying to the north of the Scandinavian land-mass, formed at a time when the Atlantic Ocean transgressed across part of the same mass from the south. This would give these limestones and the underlying sandstones the same relationship to the Cambro-Ordovicic sandstones and shales in southern Sweden that the Eriboll quartzite and Durness limestone series have to the Lower Cambric sands and to the Tremadoc and Arenig beds of the south of Britain. On this basis, the Biri limestone would have to be considered the eastward continuation of the Durness limestone, just as the Cambric and early Ordovicic beds of Sweden are the eastward continuation of the sands and shales of Wales and England formed during the same period. Whether the Biri limestone represents only the Lower Cambric portion of the Durness—that is, the Ghrudaidh and Eilean Dubh groups—or whether a part of the Beekmantown facies is also included, must remain an unsolved question until fossils are discovered. Certainly there is nothing in the physical character of the Biri limestone which

differentiates it markedly from the early portion of the Durness limestone series, and, if the correlation here suggested be correct, we may confidently expect the finding at some future time of the true Olenellus fauna along the contact of the arenaceous and siliceous beds, and probably in the lower beds of the limestone as well, where Salterella and Hyolithes should occur. Nor is it impossible that some future favorable exposures of the higher parts of the limestone will reveal the presence in it of a scattered Beekmantown fauna such as has been obtained from the Durness limestone.

The alternative correlation favored by Rothpletz is that the limestones represent a local calcareous accumulation during Cambric time, while the darker muds of Sweden were deposited farther east, both, however, belonging to the same province. Such an interpretation presents some formidable difficulties, not the least of which is the determination of the source of the material in a region characterized everywhere else by mud deposition. One might, perhaps, refer the deposit to a supermarine origin, either in a playa lake or a river floodplain. But while this would explain the peculiar characters of the deposit and its lack of organic remains, it does not solve the mystery of the origin of the calcareous sediment, nor of the absence of clastic siliceous material in it.

Lower Ordovicic of the Atlantic Region

TREMADOC

The Lower Ordovicic of Britain begins with the Tremadoc series. This is a purely clastic series of terrigenous origin, typically seen in Carnarvonshire, North Wales, and extending into Merionethshire. It consists mainly of dark gray shales, which have a total thickness of about 1,000 feet and carry an abundant fauna. Two divisions are recognizable—a lower, with *Dictyonema socialis* (*D. flabelliforme*), and an upper, with *Asaphellus homfrayi.* Besides the Dictyonema, the lower division carries a trilobite fauna, in which *Niobe homfrayi, N. menapiensis, Psilocephalus innolatus, Angelina sedgwicki,* and *Asaphellus affinis* predominate. These shales are also found in the Malvern Hills, where they are 1,300 feet thick (Bronsil gray shales), but include about 300 feet of diabases and basalts. Since these beds carry the Dictyonema fauna throughout, they are believed to represent the Lower Tremadoc only.

In the Lake District of North England the Tremadoc rocks are included in the great shale series forming Skiddaw Mountain, as shown by the occurrence of Bryograptus in a part of this series. In Scotland these strata appear not to be developed, and we may infer that an old Ordovicic

land-mass—*Caledonia*—limited the English Sea, or more properly Channel, on the north. On the south, in Normandy and Brittany, these beds are likewise wanting, for here the Grès Armoricain, the chief representative of the Arenig, either rests directly on the crystallines or is preceded by red shales of continental origin, which range up to 2,500 meters in thickness, and generally follow on a basal grit and conglomerate, the thickness of which may reach 500 meters or more. A part of this series probably represents continental Cambric, but some of the red shales, marked by Scolithus, *Tigillites linearis,* and *Vexillum desglandei,* may represent Lower Arenig or Tremadoc.

This southern region of continental deposition constituted the old landmass of *Armorica* and separated the Ordovicic English Channel from the Mediterranean Basin. For on its southern border, near Cannes and Saint Chinian, in Montagne Noire, we find the Cambric succeeded by beds of Tremadoc age, carrying, however, a series of fossils distinct from those found in the northern area and described and named by Munier-Chalmas and J. Bergeron. These are: *Euloma filacovi, Agnostus ferralsensis, Megalaspis filacovi, Asaphelina barroisi, Dictyocephalites villebruni, Dicellocephalus ? villebruni,* and *Bellerophon oehlerti.* These beds are followed by blue shales with *Asaphelina miqueli* J. Berg., *Niobe lignieresi* J. Berg., and these by black shales with *Amphion escoti* J. Berg. and other fossils. These are succeeded by the Tetragraptus shales. In Spain, near Barcelona, the Tremadoc is likewise represented by shales carrying *Ogygia* cf. *desiderata* Barr., *Asaphellus* cf. *solvensis* Hicks, *Asaph. innotatus* Barr., *Asaph.* cf. *wirthi* Barr., *Niobe* cf. *homfrayi* Salter, etcetera. Elsewhere, however, this horizon seems to be overlapped by the Arenig (Grès Armoricain).[11]

ARENIG

General discussion.—Above the Tremadoc follow the Arenig shales and grits with apparent conformity and with a maximum thickness of 2,000 feet. This series, besides containing a number of brachiopods (Lingula, Orthis, etcetera) and trilobites (Æglina, Barrandia, Calymene, Illænus, Trinucleus, Placoparia, etcetera), is especially characterized by graptolites. The series is separable into a lower or Tetragraptus zone, containing *T. serra* (= *bryonoides*), *T. quadribrachiatus, Didymograptus extensus, D. pennatulus,* and the genera Retiograptus, Loganograptus, Clonograptus, Schizograptus, and Dichograptus, mostly types characteristic of our Lower Deepkill shales of the Hudson Valley. The Upper Arenig is characterized by *Didymograptus bifidus, D. patulus, Climaco-*

[11] A. Douvillé: Handb. Reg. Geol., Bd. iii, 3, Heft 7.

graptus conferta, and *Diplograptus dentatus.* The first of this series is diagnostic of our Middle and the last of our Upper Deepkill zone, the Deepkill on the whole being thus equivalent to the Arenig.

While in the Hudson Valley the Upper Deepkill beds appear to be succeeded disconformably by the Normanskill beds of Upper Chazy or Black River age, the Arenig of Wales seems to be conformably succeeded by the Llandeilo. No positive evidence is at present available to show whether there is or is not a hiatus between these two formations in Britain, but I am inclined to think that careful search will reveal its existence in some sections. In South Wales the Llandeilo has a thickness of 2,000 feet and is divisible into the following members:

	Feet
Upper Llandeilo slates	1,000
Llandeilo limestone	200
Lower Llandeilo slates	800

The lowest zone of the Llandeilan is characterized by *Didymograptus murchisoni*, the Middle by *Diplograptus foliaceus* and *Climacograptus scharenbergi,* and the Upper by *Cryptograptus tricornis, Climacograptus scharenbergi, Cœnograptus* (*Nemagraptus*) *gracilis,* and *Dicellograptus sextans.* This association of species in the Upper Llandeilo is also characteristic of the Normanskill beds of New York, which thus appear to represent the exact equivalent of the Upper Llandeilo. Characteristic Lower Llandeilo trilobites are *Asaphus tyrannus, Calymene cambrensis, Trinucleus lloydii,* and *T. favus,* while those of the Upper Llandeilo include *Barrandia cordai, Cheirurus sedgwicki,* and *Ogygia buchii.*

Scotland.—In the southern uplands of Scotland both Arenig and Llandeilo rocks are present. The former are represented by radiolarian cherts and by mudstones of unknown thickness. They appear to overlap the Tremadoc and probably represent only a part of the Arenig series. In Dumfriesshire they are complicated by volcanic flows, which also overlie and separate them from the Llandeilo. There seems to be a disconformity in this region between the Arenig and the overlying Glenkiln shales, which carry a Normanskill or Upper Llandeilo fauna.

The disconformity and hiatus is well marked in the Girvan district of southwest Scotland (Ayrshire), where the Lower Llandeilo is overlapped by the Upper, which rests with a basal conglomerate on the Arenig cherts.

The Arenig or Ballantrae series contain:[12]

Phyllograptus typus Hall
Tetragraptus quadribrachiatus Hall

[12] Charles Lapworth: On the Ballantrae rocks of south Scotland and their place in the Upland Sequence. Geological Magazine, n. s., Dec. 3, vol. vi, 1889, pp. 20-27 (22).

T. bryonoides Hall (*T. serra*)
T. fruticosus Hall
T. bigsbyi Hall
Didymograptus extensus Hall
D. bifidus Hall
Caryocaris wrightii Salter
Dictyonema, Lingula, and Obolella.

D. bifidus is an Upper Arenig type, but it is probable that this series of rocks is Lower Arenig, as indicated by the other species.

The Llandeilo is here represented by the *Barr Series,* which comprises the following members, in descending order:

7. Benan conglomerate	1,000 feet plus
Stinchar calcareous group:	
6. Green mudstones and shales with	
1. *Didymograptus supertis* Lapw.	
2. *Dicellograptus sextans* Hall	
3. *Clathrograptus cuneiformis* Lapw.	
4. *Glossograptus hicksii* Hopk.	
5. *Cryptograptus tricornis* Carr.	
6. *Diplograptus rugosus* Emm.	30 feet
5. Compact limestone with few fossils, including Saccamina and Girvanella.	
4. Nodular, flaggy Maclurea limestone and shales with *Maclurea logani, Tetradium peachi,* etcetera. Thickness of 5 and 4 about	70 feet
3. *Orthis confinis beds*, flaggy, impure, calcareous, with *O. confinis* Salter, *O. alternata* (Salter), *Strophomena grandis* (Salter). Thickness	60 feet
Kirkland group:	
2. Purple sandstones and grits, with occasional *Orthis confinis* and *Strophomena*	40 feet
1. Purple conglomerate	150 feet plus

The conglomerate rests on the eroded surface of the Lower Arenig and consists of worn fragments of these rocks and the volcanics associated with them. It contains pebbles of chert, black shale, lavas, and tuffs, "together with serpentine, gabbro, dolomite, and even granite."[13] The calcareous beds make correlation with other horizons possible. The flags with *Orthis confinis* also contain *O. calligramma* (Dalm.) in some sections, together with *O. flabellulum* (Sow.) and *Strophomena expansa* (Sow.). The first of these is wide-spread, occurring in the Baltic provinces of Russia in horizon B III and C (see postea). *O. flabellulum* is

[13] Peach and Horne: Loc. cit., p. 484.

found in the Lower Lykholm beds of Esthonia, which, according to Bassler, correlate with our Lower Trenton. *Strophomena expansa* occurs even higher than this, being found in Esthonia in the Borkholm limestone, which is regarded as late Ordovicic. *Maclurea* (*Maclurites*) *logani* Salter is found in North America in the Black River beds of Allumette Island, Ottawa River (Leroy horizon) and the Mingan Islands, Canada, and also in Bessels Bay, Arctic America. It appears thus to belong to the fauna entering North America from the Atlantic. *Tetradium peachi* Nich. and Eth. is now referred to *Solenopora compacta* (Billings), a form widely distributed in the Middle and Upper Ordovicic, especially in the Black River and Trenton of eastern North America. *Nidulites favus* (Salter), which also occurs in this limestone, has been obtained from similar beds in Quebec. The graptolites of formation 6 are mostly typical of the American Normanskill fauna, all but number 4 having been recorded from this country.

According to this standard, then, our Normanskill fauna should lie *above* the Black River fauna and represent essentially early Trenton—a conclusion reached likewise by Ruedemann.

The Benan conglomerate (7) rests disconformably on the Stinchar group, cutting across the graptolite shales on which it rests at Benan Burn, until at Auchlewan Burn it rests on the eroded surface of the Stinchar limestone (No. 5). This descent across the graptolite shales occurs within a distance of 200 yards. The conglomerate in places is almost destitute of bedding planes, except by the arrangement of pebbles into lines in some cases. It furthermore contains fragments of the limestone.

The matrix of the conglomerate is derived from the disintegration of the basic igneous rocks of the region. The pebbles, often of the size of boulders and generally well rounded, are derived from the Arenig volcanic plateau. The disconformity does not necessarily mark a hiatus of great extent, since the conglomerate is a continental deposit which was spread out over the marine series, the terrestrial sediments pushing back the seashore as they advanced. This conglomerate marks the inpouring of a mass of coarse river sediment at this place from the highland lying to the northwest, which had been elevated, and it corresponds essentially to the conglomeratic deposits built into the retreating Ordovicic sea in North America, but derived from the Appalachian land on the southeast. The formation of the American representative, however, the Bald Eagle conglomerate, began somewhat later than the Benan, which is regarded as closing the Llandeilan stage, while the Bald Eagle is post-Trenton. That the region was again submerged in Caradocian time is shown by

the presence above the Benan conglomerate of the extensive series of Caradocian sediments with marine fossils, whereas in America emergence continued during the equivalent Upper Trentonian time.[14] The Benan conglomerate overlaps the earlier Llandeilo beds southward, where it comes to rest directly on the disturbed and eroded surfaces of the Arenig volcanics.

Lake District.—It is possible that the whole of the Arenig is represented in the great series of Skiddaw shales in the Lake District, and some Llandeilo may even be included in the upper part of the series. Most of Llandeilo time, however, was occupied by the eruption of the great Borrowdale volcanic series, which continued into Caradocian time, for late Caradocian strata alone succeed this series. This region was thus probably land during the whole of Middle Ordovicic time, as there is no reason to assume that the eruptions were of a submarine character.

Wales.—In the Welsh region, on the other hand, deposition seems to have been continuous from Arenig into Llandeilo time, as indicated by the transitional facies for which Hicks has coined the term *Llanvirn* series. This comprises some 2,000 feet of shale near Saint Davids.[15]

Normandy and Brittany.—Turning now again to the southern border of the English Lower Ordovicic sea, we find the Arenig represented in Normandy and Brittany by the Armorican grit (Grès Armoricain), a formation consisting mostly of white quartzite and ranging in thickness up to 500 meters in Brittany,[16] and well exposed along the coast of the Crozon Peninsula between the Rade de Brest and the Baie de Douarnenez. The beds of this region are thrown into a series of isoclinal folds which have a steep dip to the north, the southern limbs of the folds being overturned and the whole complicated by faults and by diabase dikes and other intrusives.

The general strike is east-west, though pronounced local variations occur. In this section the Armorican grit rests with a disconformity on the Upper Cambric Lingula sandstones (schistes pourprés), which in turn rest on the Paradoxides beds, and these are disconformably preceded by the Brioverien series of phyllites, sandstones, conglomerates, and calcareous beds (also called the Phyllades de Saint Lô), the oldest sedimentaries of Brittany and regarded as of pre-Cambric age. The Ordovicic series begins with the Erquy pudding-stone, a coarse conglomerate composed of fragments of the sediments and eruptives of the Cambric. This is followed by a coarse-grained, feldspathic, non-fossiliferous grit,

[14] A. W. Grabau: Early Paleozoic delta deposits. Bull. Geol. Soc. Am., vol. 24, pp. 399-528.

[15] Hicks: Pop. Science Review, 1881, p. 289.

[16] Ch. Barrois: Guide de Bretagne, p. 10.

which has been regarded as representative of the Tremadoc, and is, in any case, a continental formation. Above this lies the Armorican grit proper or the "grès du Toulinquet" with intercalated shaly beds. This series contains fossiliferous members, some of them truly marine and others of shore or possibly supra-marine types. Among the latter are numerous trails and other markings generally preserved in relief, such as *Tigillites dufrenoyi, Cruziana furcifera, C. prevosti, C. bagnolensis, Vexillum* sp., *Dædalus, Lumbricaria,* etcetera, while the former include many species of *Lingula* (*L. lesueri, L. salteri, L. hawkei,*[17] etcetera) and *Dinobolus bimonti.* It further contains the pelecypods *Lyrodesma armoricana, Modiolopsis caillandi, Ctenodonta costæ, Nuculana incola,* and *Actinodonta cuneata,* while the trilobites are represented by *Ogygia armoricana.* The horizon here indicated is probably Lower or early Middle Arenig. The Armorican sandstone is disconformably succeeded by the "Schistes d'Angers." These comprise, accordang to Kerforné, the following divisions, in descending order:

6. RAGUENEZ SHALES. Black shales with *Acaste proœva* and *Synhomalonotus arago* (a fauna originally described from Spain by Verneuil and Barrande).
5. KERARMOR SHALES. Black shales with *Trinucleus bureaui.*
4. MORGAT SHALES with *Placoparia tourneminei, Asaphus glabratus, Acaste phillipsi* (a fauna originally described by Sharpe from Portugal).
3. KERARVAIL SANDSTONE.
2. SION SHALES with *Synhomalonotus tristani, Asaphus guettardi, Calyx murchisoni.* This is also the horizon of *Didymograptus geminiformis.*
1. BED OF OOLITIC IRON ORE.

Disconformity.

ARMORICAN GRIT.

The fauna of these shales suggests early or Middle Llandeilo, corresponding approximately to Dd γ of the Bohemian series. The Angers shales are succeeded by the *Saint Germain sur Ille sandstone,* which Barrois correlates with the Glenkiln beds of Scotland. It is a shaly micaceous sandstone containing Diplograptidæ, *Synhomalonotus arago, Acaste incerta,* and *Trinucleus.* The highest Ordovicic division of Brittany is the Rosan limestone with a Caradoc fauna, including *Orthis actoniæ, Triplesia spiriferoides,* and *Trinucleus.*

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[17] This species is reported by Van Ingen from oolitic hematite at the top of his Bell Island Series, at a horizon which he places between the Middle and Lower Arenig.

In Normandy the Cambric, when present, rests with an unconformity on the folded and eroded "phyllades de Saint Lô" of Algonkic age. In the province of Orne the Grès Armoricain rests disconformably on the Cambric, but in the southern part of the adjoining province of Manche it rests unconformably on the Saint Lô phyllites, the Cambric, if deposited here, evidently having been eroded before the deposition of the Armorican sandstone. Moreover, the Armorican sandstone has a transgressive character and varies in thickness from 12 to a maximum of 500 meters. It is followed disconformably by the Angers roofing slates (Schistes à Calymène), with a thickness of 30 meters or less, which contain in their basal part *Didymograptus geminus* and *Calymene aragoi*, and *Calymene tristani* and *Trinucleus bureaui* in the upper part. Other species are: *Dalmanites phillipsi, Uralichas ribeirei, Asaphus guettardi, Illænus giganteus, Placoparia tourneminei, Cheirurus andegarus*, ostracods, cephalopods, pelecypods, and brachiopods, including *Orthis budleighensis.* Near Caen (Calvados) the Angers slates are succeeded by the May sandstone (grès de May), which still contains in its lower part *Calymene tristani* and is otherwise rich in trilobites.

In the valley of the Mayenne the pre-Cambric beds are succeeded, apparently with a disconformity, by the Gourin pudding-stone, and this by the Armorican sandstone, the Cambric being absent here. That the Cambric formerly extended over much of this region is shown by its presence in the basin of Laval, which lies between this region and southern Manche (Mortain), where the Cambric is likewise absent, though to the east in Orne it is again present. From this we may conclude that the epoch of the Armorican grit was preceded by one of erosion, which removed the Cambric formations from parts of this region. This is also shown by the conglomeratic character of the base of the Armorican, where it rests on the Cambric (see in Brittany). The Armorican sandstone and the succeeding Angers slates with *Calymene tristani* are here much thinner, the hiatus between them being greater than farther north. At Montigné, on the southern flanks of the Laval basin, the Armorican sandstone is reduced to a few thin, sandy beds with *Lingula lesueuri.* This rests without the basal conglomerate on the pre-Cambric beds, apparently with a disconformity, and is succeeded by the Angers series, somewhat slaty, very black, and poor in fossils. This is followed by the Saint Germain-sur Ille sandstone with *Orthis berthoisi* var. *erratica.*

These sections thus indicate a transgression of the sea from the north over the old Armorican land-mass which included the central area of France. After the deposition of the Armorican sandstone, the sea again withdrew, to return in mid-Ordovicic time, when the Angers argillulites

(now slates) were deposited. The hiatus between the Armorican sandstone and Angers mudstones corresponds to the hiatus between the Lower Arenig and the Glenkiln of Scotland, and this indicates that the retreat of the sea at the end of Arenig time resulted in a narrowing of the English Channel. Whether the British area emerged completely, so that a continuous land-mass extended from the old land of Scotland (Caledonia) to France (Armorica) must be determined by a further study of the Welsh sections. If these, too, show a hiatus between the Arenig and Llandeilo, such complete withdrawal of the sea would be indicated. The fact that in South Wales the Upper Arenig and Lower Llandeilo form apparently a unit, the Llanvirn group of Hicks, 2,000 feet thick, near Saint Davids, indicates that here at any rate deposition was continuous. This does not argue, however, for continuity to the east of this, for there dry land probably existed, as is indicated by the conditions in the Baltic region, to be discussed subsequently in this paper. The southern Wales district may have constituted an embayment from the Atlantic Ocean of Llanvirn time.

Mediterranean Region

Iberian Peninsula

On the southern border of the ancient Armorican land-mass, or the Iberian Peninsula of early Ordovicic time, the Tremadoc beds, as already noted, are found at Montaigne Noire in southern France and at Barcelona in Spain; but inland (northward and westward) they are overlapped by the transgressing Arenig, here also represented by rocks of the Armorican sandstone type. Much, if not all, of the southern part of the peninsula (Spain and Portugal) seems to have been covered by the Arenigian during its greatest advance; but central France probably remained above water. With the succeeding retreat of the sea, however, the whole of this region seems to have been uncovered again, for even at Barcelona the Armorican sandstone is only slightly developed, having probably been in part removed by erosion during the retreat. More evident, however, of the presence of a hiatus between it and the succeeding beds is the fact that it is followed by beds with *Orthis actoniæ* Sow., *O. vespertilio* Sow., *O. calligramma* Dalm., *O.* (*Dalmanites*) *testudinaria* Dalm., *Plectambonites sericeus* Sow., *Echinophærites* cf. *balticus*, etcetera, these clearly proving Caradoc age for these beds. Thus the Llandeilo is absent altogether, being overlapped by the Caradoc, which probably represents a continuation of the transgressive movement begun in Llandeilan time. Speaking in terms of the American series, beds of early Beekmantown age are here followed by Middle Trenton, a condition not infrequently

found in some American sections, and due to the same eustatic movement.

In the Iberian chain of the ancient province of Aragon the Armorican sandstone is only about 30 meters thick and rests on a ferruginous upper member of the Cambric, the hiatus between the two being somewhat marked. This is followed by the Angers slates, 25 to 30 meters thick, and characterized by *Calymene tristani* Bron., *Orthis budleighensis* Dav., *Redonia,* etcetera. A 12-meter bed of unfossiliferous quartzites separates this from shales with *Orthis actoniæ* Sow., *O. alternata* Sow., *Orthis budleighensis* Dav. This is probably the Ashgill horizon. Beds of this age with *Orthis actoniæ, O.* cf. *vespertilio, Strophomena expansa, Tentaculites, Chætetes, Favosites,* and *Strophostylus* form the oldest fossiliferous horizon of the Pyrenees.

In the Sierra Morena and the mountains south of Toledo beds of the age of the Angers slates and the May sandstone (Llandeilo) are known, resting on a thin quartzite with Cruziana, which may represent a part of the Armorican grit. The Arenig series seems to be largely wanting here, either through non-deposition or on account of erosion during the retreatal interval.

The fossils found in the Ordovicic beds of this southern half of Spain are all from the beds belonging to the higher or retransgressive series. These include:

Placoparia tourneminei M. Rouault.
Cheirurus marianus de Vern.
Homalonotus rarus Corda.
H. brongniarti Desl.
Calymene pulhra Barr.
C. (*Synhomalonotus*) *tristani* Brong.
C. aragoi M. Rouault.
C. tristani de Vern. et Barr.
Dalmanites socialis Barr.
D. downingiæ Murch.
D. vetillarti M. Rouault.
D. torrubiæ de Vern. et Barr.
D. phillipsi Barr.
D. dujardini M. Rouault.
Lichas hispanica de Vern. et Barr.
Trinucleus goldfussi Barr.
Asaphus nobilis Barr.
A. cianus de Vern. et Barr.
Asaphus contractus de Vern. et Barr.
A. glabratus Sharpe.
Illænus hispanicus de Vern. et Barr.
Ill. sanchezi de Vern. et Barr.

The close relation of these faunas to those of the Bohemian series D 2 to D 4 is apparent, while at the same time its distinctness from that of the Baltic region is seen.

The Ordovicic beds of northwest Spain, in the provinces of Galicia and Asturia, belong to the series of deposits formed on the northwestern flanks of the Armorican land-mass, in continuation of those of Brittany. In both regions the Cambric begins with the Rivadeo series, consisting of about 3,000 meters of green, greenish, or bluish shales and quartzites, and resting on the pre-Cambric, which in some sections are said to pass upward into the Cambric beds. This is followed by the Vega series, beginning with a bed of iron ore 1 to 2 meters thick, followed by a limestone 20 to 60 meters in thickness, and then by fossiliferous greenish shales and quartzites from 50 to 100 meters thick. This latter series carries the Paradoxides fauna. Above this follows the Cabo Busto sandstone, which generally begins with a pudding-stone, and reaches the great thickness of 1,500 meters in Galicia. It contains Scolithes and Cruziana (Bilobites) and represents the basal Ordovicic, which thus rests disconformably on Middle Cambric. The formation is mostly continental in origin, though in Asturia some of the lower beds contain *Lingulella heberti*. The Cabo Busto sandstone is also terminated by a thin bed of iron ore, above which lie the Luarea shales, the essential equivalent of the Upper Angers slates. These are 100 meters thick at Cap Vidrias and contain *Calymene* (*Synhomalonotus*) *tristani, Asaphus glabratus, Dalmanites phillipsi, Bellerophon bilobatus, Redonia, Echinosphærites murchisoni,* etcetera. This corresponds approximately to the Sion shales of Brittany and in a general way to the early Trenton of North America.

MONTAGNE NOIRE, SOUTHERN FRANCE

We have already seen that representatives of the Tremadoc are found here, lying on the Cambric, probably with a disconformity. "They pass upward into the *Boutoury shales* with Tetragraptus, Didymograptus, and *Rouvillograptus richardsoni* Barr., as well as trilobites. These represent the early Deepkill beds of America, and they are succeeded by sandstones with *Vexillum, Cruziana, Lingula lesueuri* Rou., and other species, and occasionally *Dinobolus brimonti* Rou. This represents the Armorican sandstone of northern France and Spain. It is extremely unlikely that the Armorican sandstone extended entirely across France. The old Armorican land-mass probably remained intact through Arenig time, and the migration of the fauna into the Mediterranean region was around the southern end of the peninsula.

BOHEMIA

In portions of the Bohemian basin the Middle Cambric Skrej Jinetz formation of Bohemia is followed with a marked disconformity by the sandstones of the Krŭsnáhora formation (D 1 α), which are characterized by *Lingula feistmanteli.* These beds have often been placed in the Upper Cambric, but they are more properly classed as basal Ordovicic. Marr considers that *L. feistmanteli* "is very near to the remarkable *Lingula roualti* of the Armoricain grit."[18] He concludes that these beds are therefore late Arenig, the Lower Arenig and Tremadoc being absent in Bohemia.

The Krŭsnáhora beds are quartzites, often glauconitic graywackes, shales, and hornstones. These Krŭsnáhora beds are absent throughout the Jince district of the Bohemian basin, where the Paradoxides beds are either followed by the ironstone-bearing zone of *d* 1 β or by *d* 2.[19] The Lower Ordovicic division, which is most wide-spread in Bohemia, is the Komorau formation or *d* 1 β of Barrande. This consists of black shales, hematite ironstones, diabase, and diabase tuffs, the total not exceeding 100 meters. It often overlaps the Krŭsnáhora beds, resting directly on the Middle Cambric. The fossils found in this formation include:

Orthis desiderata Barr.,
Lingula,
Harpides grimini,
Amphion (Pliomera) lindaueri, and
Didymograptus (Isograptus) caduceus (Salter).

The graptolite indicates Lower Deepkill for this series, and this is not negatived by the other species. Marr would refer this division "to a position high up in the Arenig series." Here he would also place the next succeeding Kván-oseker beds *d* 1 γ of Barrande, dark, mostly black clay shales, and graywackes, with sandy intercalations. They contain:

Placoparia zippei,
Ogygia,
Asaphus nobilis,
Illœnus katzeri,
Bohemella,
Dalmanites,
Niobe discreta,
Æglina prisca,
Riveiria,
Orthis, and
Didymograptus geminus.

The graptolite marks this horizon as of Lower Llandeilo age, the hiatus between it and the preceding Komorau formation (*d* 1 β) including at least Middle and Upper Arenig. These mid-Ordovicic beds are succeeded

[18] Geol. Mag., Sept., 1889, decade iii, vol. vi, p. 413.

[19] Jaroslav J. Jahn: Geologische Exkursion im Älteren Palæozoikum Mittelböhmens. Führ. Cong. Geol. Int., IXe session, pp. 42-45; footnote.

by Barrande's Division D_2, the Drábover beds, consisting of quartzites, quartzitic sandstones, and clay shales. The series appears to be conformable with the Kván-oseker beds, some of the species of the latter continuing upward into the Drábover beds. This horizon is characterized by *Dalmanitina socialis* Barr., *Trinucleus goldfussi* (which continues upward into D 3), *Asaphus nobilis, Homalonotus,* etcetera.

These beds represent the Upper Llandeilo horizon. Above them follows with apparent conformity the Trubiner black shales, with occasional intercalations of thin beds of grit (D_3), and the Zahoraner grits and shales (D_4). Both these formations contain *Trinucleus concentricus* (*T. ornatus*) and represent approximately the horizon of the American Trenton and the British Caradoc. Overlying this are the Königshofer shales and Kosover quartzites with *Trinucleus seticornis,* etcetera, which constitute the highest Ordovicic, and are followed disconformably by the Siluric.

The Bohemian series extends into the adjoining region of Bavaria, where, near Hof, the Cambric shales are followed disconformably by the Leinitz shales carrying *Orthis* cf. *desiderata* Barr. and corresponding to the Bohemian D *d* 1 β. Higher Ordovicic beds are not represented there by fossiliferous strata.

Lower Ordovicic of the Baltic Region

THE ORTHOCERAS LIMESTONE

This name is in general use in the Scandinavian region for a limestone series included within the graptolite-bearing shales of the Ordovicic. The name is applied in different sections to limestones not always covering the same geological interval, since some of the subdivisions found in one section may be wanting in another, or may there be replaced by graptolite-bearing shales. In the province of Esthonia, on the German-Russian side of the Baltic, similar limestones are developed, though they are perhaps less frequently known by the name of Orthoceras limestone. I have had an opportunity to study these rocks under the guidance of several Swedish geologists in the provinces of Westergotland, Dalarne, and Scania, and have had occasion to consult the recent literature on these as well as the Norwegian and the Esthonian regions.

A typical section of this formation is furnished by the classical exposures in the hill known as the Kinnekulle on the southeastern side of Lake Venern, near Rabäck station. This hill and its rich yield of Paleozoic organic remains was first made known by the work of Kalm in 1742 and of Linnæus in 1747, and has since been the object of study of many an eminent investigator, both native and foreign. Angelin in 1852 made

the first paleontological subdivision of the strata of this region, and on this is based practically all of the subsequent work. But it was Gustav Linnarsson, a native of Westergotland, who, in 1869, in his work, "Om Vestergötlands Cambriska och Siluriska aflagringar," placed the knowledge of the geological succession of this province on a modern basis, and so laid the foundation for subsequent study of the Paleozoics of Sweden.[20]

Extensive studies of this section were made by G. Nathorst, 1881; G. Holm and H. Munthe, 1901, and by Munthe, 1906; by Wiman, 1910, and by others.

The entire section of the Kinnekulle is as follows, in descending order, chiefly after Wiman, with observations of my own added:

Diabase (intrusive) forming the top of the hill.............. 30 m.+

Siluric (Upper Llandovery).

Upper Graptolite shales, 56 m., divisible into—

b. *Retiolites shales* with *Retiolites geinitzianus* Barr., *Monograptus crenulatus* Tqt., *M. priodon* Bronn, *M. culellus* Tqt., and *M. subconicus* Tqt.

a. *Rastrites shale* with *Rastrites hybridus* Lapw. and with *Monograptus runcinatus* Lapw., *Diplograptus* (*Cephalograptus*) *cometa* Gein., *D.* (*Petalograptus*) *folium* His., and *Monograptus triangulatus*, Harkn.

Hiatus.

Ordovicic.

Brachiopod shale, a calcareous shale passing upward into a sandstone and carrying *Dalmania mucronata* Brgn., *D. pulchella* Lns., and *Homalonotus platynotus* Dalm.............. 2 m.

Trinucleus shale, comprising

Red Trinucleus shale with *Remopleurides radians* Barr., *Cybele verrucosa* Dalm., *Trinucleus wahlenbergi* Rault, *Ampyx tetragonus* A., *Dionide euglypha* A., *Agnostus trinodus* Salter, etcetera........................ 18 m.

Limestone stratum.............................. 2 m.

Black and green Trinucleus shales................ 12 m.

Total Trinucleus shale........................... 32 m.

Chasmops beds, dark shales with graptolites and numerous concretionary limestone masses and beds of impure limestone containing *Chasmops* sp. *Remopleurides sexilineatus* A., *Ptychopyge glabrata* A., *Ampyx rostratus* Sars., *A. costatus* Boeck., *Agnostus trinodus* Salter, *Beyrichia costata* Lns., *Primitia strangulata* Salt., and numerous *Echinosphærites aurantium* Gyllenh., especially in the lower part............ 10 m.

[20] K. Swenska: Vetenskaps Akademiens Handlingar, Bd. 8, No. 2, Stockholm, 1869.

Orthoceras limestone, comprising—

(*d*) *Upper gray* or Chiron limestone with *Illænus chiron* Hm., *Ogygia dilatata* Brünn var. *sarsi* A., *Ancistroceras undulatum* Boll., and *Discoceras teres* Eichw.. **10 m.**

(*c*) *Upper Red*, including—

$(c)_2$ *Platyurus limestone* with *Asaphus platyurus A.* and *Orthoceras tortum* and

$(c)_1$ *Gigas limestone* with *Megalaspis gigas.*[21]

Total c_1 and c_2...................... 24 m.+

(*b*) *Lower gray* or *Asaphus limestone* with numerous fossils, including *Cyrtometopus clavifrons* Dalm., *Phacops sclerops* Dm., *Asaphus raniceps* var. *maxima* Br., *Megalaspis heros* Dm., *M. rotundatus* A., *M. explanata* A., *Illænus esmarki* Schloth, *Ampyx nasutus* Dm., *Endoceras wahlenbergi* Foord, *Orthoceras kinnekullense* Foord, *Estonioceras proteus* His., *Bathmoceras linnarssoni* A., *Gonionema bicarinatum* His., *Raphistoma gradatum* Koken, *Orthis* sp. and *Sphæronis pomum* Gyllenh., the latter in rock-forming quantity .... 6 m.

(*a*) *Lower red* or *Limbata limestone* with *Megalaspis limbata* S. & B. and *Nileus armadillo* Dm............. 12 m.

Total Orthoceras limestone.................. 52 m.+

Lower Didymograptus shale, light greenish gray shale with *Phyllograptus densus* Tqt., *Didymograptus extensus* Hall, *Tetragraptus quadribrachiatus* Hall, and *T. fruticosus* Hall.. 10 m.

Planilimbata limestone, gray limestone with *Megalaspis planilimbata*, *Eorthis christianæ*, etcetera...................... 0.5 m.

Ceratopyge limestone, upper part glauconitic limestone, with *Ceratopyge forficula* Sars., *Euloma ornatum* A., *Cyrtometopus primigeus* A., *Niobe insignis* Lns., *Symphysurus angustatus* Boeck, *Nileus limbata* Brögg, and *Eorthis christianiæ* (Kj.), *lower part* glauconitic shale with *Lycophoria lævis* Stolley... 2 m.

Total shales and limestones......................... 12.5 m.

Hiatus? with Dictyonema shales wanting—possibly replaced by Lower Ceratopyge limestone.

Cambric.

Upper Cambric alum shale containing in the upper beds *Peltura scarabioides* Wbg. and *Sphæropthalmus alatus* Boeck; a phosphate conglomerate with *Orthis lenticularis* and fetid limestone layers (1.6 meters thick), some beds of which are

[21] This species has not been reported from the Kinnekulle, but occurs elsewhere in Wester-Gotland.

entirely composed of *Agnostus pisiformis* L. and others largely of *Olenus gibbosus* Wbg. *A. pisiformis* also occurs in the lower shales..	15.6 m.
Middle Cambric Paradoxides beds—	
Not exposed at present....................................	6.4 m.
Lower Cambric, comprising	
Lingula sandstone with Lingula sp..........................	20. m.
Mickwitzia sandstone with	
Mickwitzia monilifera Lns. and *Torellella lævigata* Lns., together with impression of *Medusites lindströmi* Lns., *M. favosus* N., *M. radians* Lns., and the raised "trails" which have been referred to Cruziana—and the so-called *Eophyton*, from which this sandstone originally received its name of "Eophyton sandstone." The base is formed by a conglomerate containing "dreikanter" of quartz, of which several excellent specimens were obtained at Lugnås	10 m.
Total Cambric..................................	46 m.

Weathered gneiss, quarried for millstones.

In a small stream on the west side of the Kinnekulle near Trollmen, where the Lower Didymograptus shale was exposed with the Ceratopyge limestone below it, we found, in the upper beds of the latter, which here is a gray limestone, numerous pygidia of *Megalaspis planilimbata*, together with a few specimens of other trilobites and *Eorthis christianiæ*. This seems to indicate that this exposure is the *Planilimbata* limestone, which here appears to be continuous with the Ceratopyge limestone. To be sure, the entire mass of the limestone was not exposed, the exposures being rather a series of ledges in the small stream. This makes it possible to overlook any disconformity which might exist between the Ceratopyge and Planilimbata limestone, though certainly none such could be found after careful search. Moreover, these limestone beds evidently lay below the Lower Didymograptus shales, which were exposed farther up the hill, though no actual contact between the two series could be found; nor could a fault be assumed between the two exposures, for this would place the Ceratopyge limestone with the Planilimbata limestone *above* the Didymograptus shales. When it is remembered that the Ceratopyge beds are universally found at the base of the Ordovicic—equivalent in part to the Tremadoc of Britain and perhaps the Potsdam of North America—while the Lower Didymograptus shales are the equivalent of our *Lower* Deepkill zone, it is apparent that the Planilimbata limestone here exposed is of early Ordovicic age, the practical equivalent of our lowest Beekmantown, the Little Falls dolomite, or perhaps the Theresa or Hoyt lime-

stones, both of which form transition beds to the Lower Beekmantown or Little Falls dolomite.[22]

The great faunal difference between the West European early Ordovicic and that of eastern North America is probably to be explained by the difference in origin of the faunas, the Beekmantownian being primarily a Boreal[23] or northern fauna in the east and northeast and a South Pacific fauna in the south and west, while the West European limestone fauna is of North Pacific or of Siberian origin. The graptolite fauna, however, was undoubtedly, in part at least, existent in the Atlantic.

The close association of the Ceratopyge limestone and the limestone with *Megalaspis planilimbata* in the Trollmen region above noted, and the occurrence of the Lower Didymograptus shales above it, precludes the possibility of the existence of a pronounced hiatus (if any) between the Lower Red Orthoceras limestone (*Megalaspis limbata* limestone) and the Lower Didymograptus shale, because *M. planilimbata* and *M. limbata* are found associated in the same beds in regions where the Lower Didymograptus shale is wanting as in Dalarne, discussed further on. It would thus appear that the Lower Didymograptus shale, when present, replaces a part or all of the Planilimbata limestone and perhaps a part of the Limbata limestone as well. Farther east, in Westergotland, at Œdegarden, the Lower Didymograptus shale is wholly replaced by the *Megalaspis planilimbata* limestone, which, as we were able to judge under the expert guidance of Professor Wiman, is here intimately associated with the Ceratopyge limestone, which in turn rests disconformably on the Upper Cambric Stinkkalk with Peltura and Sphæropthalmus.

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[22] I am well aware that Ulrich separates the Little Falls dolomite from the Beekmantown and refers it to his Ozarkian. I have not yet seen any evidence which makes the separation of the Ozarkian as a distinct system permissible. The Little Falls dolomite, in my view, represents the transgressive portion of the early Ordovicic (Beekmantownian of my classification) which culminated with the deposition of the Tribes Hill limestones, which I consider as essentially continuous with the Little Falls dolomite. During the early regressive phase of the Beekmantownian, beds similar to the Little Falls in lithic character were probably deposited above the Tribes Hill in the Mohawk Valley, but these were eroded during the long interval of exposure between the retreat of the sea in early Beekmantown and its return to the Mohawk region in late Chazyan time (Lowville). During this interval the Tribes Hill was also removed by erosion in the eastern portion of the Mohawk Valley, for it is extremely unlikely that that region escaped its deposition during the later transgressive stages of early Beekmantown time. I have elsewhere given at length my views on the character of the retreat and readvance, and I have not seen anything in the new facts brought forward since that time to cause me to change them. Indeed, I find that they rather confirm my frequently expressed views in this matter, which are rather widely at variance with those expressed by Ulrich and adopted by his followers. (See my *Types of Sedimentary Overlap* and *Physical and Faunal Evolution of North America in Ordovicic and Siluric Time.*)

[23] I hesitate to speak of this fauna as of Arctic origin, for although the indications are that the present Arctic region was its home, I do not believe that that region had its present relation to the North Pole of the earth's axis. The term Boreal is therefore chosen to represent this region as being non-committal so far as polar relation is concerned.

The fauna of the *Megalaspis limbata* limestone at the Kinnekulle does not occupy the whole of the Lower Red Orthoceras limestone, for a part of this rock, according to Moberg, falls into the Asaphus limestone. G. Holm, however, makes the Limbata limestone the equivalent of the Lower Red Orthoceras limestone of the Kinnekulle quarrymen. Under the term Asaphus limestone have been included all those beds in which species of Asaphus predominate over species of Megalaspis, and it would appear that the beds designated are not always exact equivalents in different sections. At the Kinnekulle the fauna of this division differs markedly from that of the Limbata limestone, though, as will be seen by a glance at the list of the Asaphus limestone fauna given above, the genus Megalaspis is still present. Indeed, that genus ranges through a considerable portion of the Orthoceras limestone, while with us the species referred to it are confined to the lower western Beekmantown, with the exception of one species described from the Lower Richmond of Iowa.

THE ORTHOCERAS LIMESTONE OF ESTHONIA

Before considering the Orthoceras limestone of northern Scandinavia, it will be well to note the characteristics of the equivalent formations in the Baltic provinces, Esthonia and Saint Petersburg, on the south side of the Gulf of Finland, and approximately due east from the Swedish locality just discussed. This section, which I have not visited myself, has been described in considerable detail by Fr. Schmidt, and more recently by Lamanski and by F. v. Huene (Centralbl. für Min., etc., 1904, No. 15).[24]

Bassler, in an elaborate memoir on the early Paleozoic Bryozoa of the Baltic Province, gives a summary of the section and a list of the species of fossils reported from these formations with an indication of their range in the several subdivisions of the series. This list, though in some respects faulty (see the criticism by Axel Born), nevertheless is of great value, and Bassler has performed a distinct service for which students of the early Paleozoic rocks owe him gratitude.

In this region the section begins with the Lower Cambric Esthonia formation (Marcou), which rests on the pre-Cambric granite or gneiss and has a thickness of 100 meters or more. It includes a basal sandstone and an intermediate thick layer of plastic blue and greenish clay, and is followed by sandy layers with intercalated clayey layers, which carry *Mesonacis (Schmidtiellus) mickwitzi, Mickwitzia moniliforme,* and *Volborthella,*

[24] Since this paper has been completed, the important paper on "The correlation of the Ordovician strata of the Baltic basin with those of eastern North America," by Percy E. Raymond, has appeared (Bull. Mus. Comp. Zool., vol. lvi, No. 3). Reference will be made to it in the following pages in footnotes.

as well as casts of medusæ and other fossils. This appears to be the equivalent of the Mickwitzia sandstone of the Kinnekulle section. The highest beds of the series consist of from 10 to 15 or more meters of an unfossiliferous sandstone, the apparent equivalent of the Lingulid sandstone of Westergotland. There is thus clearly indicated a westward and northward transgression of the Lower Cambric sea, with progressive overlap of the strata in that direction.

Middle Cambric beds are wanting, but the Upper Cambric[25] is represented by the Ungulite sandstone, which is about 20 meters in thickness, mostly unconsolidated, and characterized by *Obolus apollinus.* This horizon is widely represented in Sweden by the Obolus conglomerate, which in some sections (see Dalarne) lies at the base of the fossiliferous series, and is there included in the Ordovicic, and in others (for example, Oeland) lies on various members of the Middle Cambric, fragments of which it includes. The Obolus is generally found in the cementing lime sand, which in some sections includes also *Dictyonema flabelliforme, Agnostus pisiforme,* and Olenus (Grünicken on Œland, Moberg, *et al*). The Obolus conglomerate sometimes includes beds carrying *Agnostus pisiformis.*

We may judge from this that the Obolus conglomerate represents the transgressing basal bed of late Cambric-early Ordovicic time, and that the Dictyonema shale which follows it in Œland and in the Baltic Provinces is the next depositional member. Bassler, in his section, indicates a hiatus between the Ungulite and Dictyonema beds, but there seems to be no evidence for such a break. When the Dictyonema shale is absent, as at the Kinnekulle and in Dalarne, this may be due to non-deposition of the shales, their place being taken by early Ceratopyge limestones. *Dictyonema flabelliforme* was an Atlantic type, as shown by its abundance on both sides of that ocean, especially in Britain and in eastern North America. Ceratopyge, on the other hand, was a Pacific or Siberian type, represented in America only in the western (Pacific) deposits. It is thus perfectly possible that in different types of sediment at one and the same period members from the faunas of distinct oceans may have become buried, while the subsequent advance westward of the Ceratopyge fauna may have resulted in the overlapping of the beds carrying this fauna over the horizon of the Dictyonema fauna. It may be noted in this connection that in parts of England (Malvern Hills) *Dictyonema flabelliforme* ranges through a thousand feet of strata, while in Sweden the beds with Ceratopyge are as a rule of slight thickness. There are, of course,

[25] Raymond includes this with the Dictyonema beds in his Packerort formation, which he makes basal Ordovicic (p. 186). The presence of *Agnostus pisiformis* and Olenus, however, argues against this.

not wanting indications of a possible hiatus between the Ceratopyge beds and the Upper Cambric strata. One such we were enabled to study at Oedegarden, near Ekedalen, in Westergotland, under the guidance of Prof. Carl Wiman, of Upsala. The section herewith given is taken from my field notes and represents the Ceratopyge limestone—here intimately associated with, and indistinguishable from, the Planilimbata limestone—resting on the fetid limestone of the Olenus-bearing Alum shale series (Upper Cambric). The fetid limestone contains Peltura and Sphærophthalmus, and its upper surface is characterized by corrosion hollows which are often several centimeters deep, and are filled by the glauconitic Ceratopyge limestone. The two are so firmly united that it was possible to remove specimens showing both beds.[26] The base of the Ceratopyge limestone is characterized by brown phosphate nodules, which contain fossils of the underlying Stinkkalk and represent altered fragments of the same.

The Dictyonema shales are here wanting, as well as the zones of Acerocare and *Parabolina heres,* which in Scania have a thickness of 5 meters, and this and the corrosion grooves suggest temporary exposure of the Upper Cambric beds. I doubt, however, if this exposure was a long one; it represents more likely one of those numerous small oscillatory movements which seem to have characterized certain portions of the old land of Cambric and Ordovicic time, on the borders of which the strata of this period were deposited.

The Ceratopyge beds seem to be wholly wanting in Esthonia, where the Dictyonema shale is also occasionally absent. It, or the Ungulite sandstone below it, is followed by glauconitic sandstone, which Lamanski designates as Division B I of his series. This reaches its greatest thickness of 5.5 meters in the western area at Baltic Port, where the rock consists of rounded quartz and glauconite grains with fragments of crystalline rock and some bituminous shale pieces. Eastward it becomes thinner and more clayey, being mostly clay with intercalated sandy loam east of Saint Petersburg.

The contact between the base of the glauconite sand and the top of the Dictyonema shale is always sharp, since there is a slight erosion hiatus between them, as indicated by evidence of erosion in the shale and the

[26] According to Michalsky, this is the usual relation when glauconite rests on limestones. It has been noted in the Schratten Kalk of Switzerland and in the Jurassic limestone near Regensburg, in addition to the Ceratopyge horizon of Sweden. (The holes are often as if made with an augur and filled with glauconite. Cong. Geol. Int. Compt. Rend., sesion Stockholm, also Andersen, Bull. Geol. Inst. Univ. Upsala.) The Regensburg occurrence I was enabled to study with some care. Here the contact is between the Regensburg greensand of Cenomanian age and the Kehlheim limestone of Upper Jurassic age.

presence of worn pieces of shale in the basal part of the glauconite sand. The latter gradually becomes calcareous upward, until beds of glauconite limestone with *Megalaspis planilimbata* become intercalated between the sands, marking the beginning of B II.

The lower part of the Glauconite sandstone, B I α, contains *Obolus siluricus,* indicating relationship to the Ceratopyge limestone, which this sandstone probably represents.

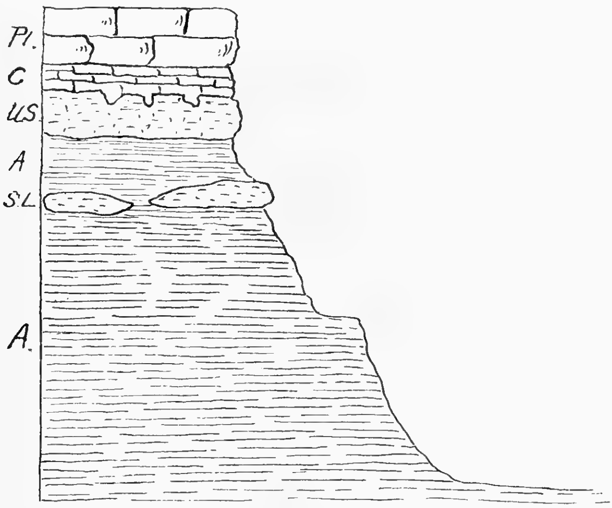

FIGURE 3.—*Section at Oedegarden, Sweden*

Showing contact between Ceratopyge limestone and Stinkkalk of the Upper Cambric. *Pl*＝Planilimbata limestone; *C,* Ceratopyge limestone; *U S,* Upper Stinkkalk; *S L,* Stinkkalk lenses; *A,* Alum shale (Upper Cambric).

The upper division, B I β, is characterized by *Megalaspis leuchtenbergi* Lamanski, a close relative of *M. planilimbata,* of which it may be a prenuncial variety. Two other species, *Megalaspis bowni* Lamansky and *Megalaspides schmidti* Lamansky, a relative of *Megalaspides delecarliens* Holm, of the Phyllograptus shale of Dalecarlia, Sweden (Dalarne), also occur here. Other species are *Ptychopyge* (?) *inostranzewi* Lamanski and *Triarthrus* (?) *angelini* Linnarss. There are, further, numerous species of Orthidæ, of which the following are described by Lamansky:

Orthis recta Pander.
striata Pander.
transversa Pander.
transversa var. *latestriata* Lamansky.
incurva Lamansky.
christianiæ Kjerulf.

tetragona Pand.
var. *lata* Pand.
abscissa Pand.
bocki Lamanski.
parvula Lamanski.

Other brachiopods are:

Porambonites bröggeri Lamansky.
Plectella gracilis Lamanski.
unicata (Pander).
semiovata Lamanski.
media Lamanski.
eminens Lamanski.
extensa Lamanski.
obtusa Lamanski.

Besides these brachiopods there occur

Orthoceras atavus Brögg.
Siphonia (?) *cylindrica* Eichw.

Lamansky finds that the brachiopods of this horizon are divisible into two groups. The species of the first group are restricted to this horizon and do not pass upward into the overlying limestone. Here belong *O. recta, O. striata, O. christianiæ,* and *O. bocki.* Only two of these are found in Scandinavia, where *O. christianiæ* occurs in the Ceratopyge limestone, while *O. recta* has been found in the Obolus sandstone near Gefle. The other species of Orthis, as well as those of Porambonites and Plectella, extend upward into the overlying Planilimbata limestone, where they are for the most part represented by closely related mutations. Lamansky holds that the brachiopods referred to Orthis sp., Leptæna sp., Strophomena sp., etcetera, from the Ceratopyge beds, and the intercalated limestones of the Phyllograptus shales of Sweden may be of species above listed. Those brachiopods are somewhat suggestive of species found in the later Ordovicic (Trenton, etcetera) of North America and the equivalent west European horizons, suggesting that this element of the fauna had its center of distribution in the northeastern region, from which successive migrant groups were sent westward throughout Ordovicic time. We can, however, not follow Bassler in placing these lower deposits in the Middle Ordovicic on the basis of these brachiopod types.[27]

Among the trilobites, *Megalaspis leuchtenbergi* shows the close relation of this division to the succeeding beds with *M. planilimbata; Triarthrus angelini,* on the other hand, is a characteristic species of the Ceratopyge limestone of Sweden. The intimate relationship with the Phyllograptus

[27] Raymond also correlates these with the lowest Beekmantown.

beds of Dalecarlia, Sweden, is shown by *Megalaspides schmidti,* the representative of *M. dalecarlicus* of the limestone bands of the Swedish Phyllograptus shale. Finally, *Orthoceras atavus* Brögger is another characteristic species of the Ceratopyge limestone, having first been described from that rock in Norway.

Altogether it would appear that Division B I of the Baltic Provinces is the equivalent of the Scandinavian Ceratopyge limestone and shale, forming the near-shore phase of that division of the North European basal Ordovicic. This is borne out by the fact that this horizon is absent in the Bohemian area, where, however, its time equivalent may be represented by the Krūsnáhora sandstone with *Lingula feistmantelli,* a fauna probably of Atlantic origin. Ceratopyge has, however, been reported from the Thuringian forest region.[28] Lamansky holds that Division B I may be in part the equivalent of the Lower Phyllograptus shales, as shown by the fact that these shales contain limestones with Megalaspides, a genus also represented in B I β. For this horizon he proposes the name *Megalaspides* zone and places it between the Ceratopyge and the Planilimbata zones.

It may be desirable to repeat here the statement made above, that the Ceratopyge fauna is of Siberian origin, entering the Baltic region from the northeast, whereas the Dictyonema and Phyllograptus-Tetragraptus faunas are of Atlantic origin (or habitation), entering the same province from the west. Thus an overlapping of the faunas occurs, though, as found in Scandinavia, the Dictyonema always underlies the Ceratopyge beds, a circumstance which clearly shows that the Ceratopyge fauna entered this region subsequent to the arrival of the Dictyonema fauna, though it probably existed at the same time in the more easterly provinces.

Since the Phyllograptus shales normally follow on the Dictyonema shales, where the Ceratopyge beds are absent, they are to be regarded as, in part at least, the equivalent of the Upper Ceratopyge beds, though a portion of the latter may also be represented by Dictyonema shale. The fact that the Phyllograptus shales disappear eastward and northward (Œdegarden, in Westergotland, and Sjurberg, in Dalarne), while they are present westward (Kinnekulle, Christiania), where the Planilimbata limestone is absent, shows the derivation of the graptolite fauna to be from the west or Atlantic region.

The North Pacific or Siberian habitation of the Ceratopyge, as well as the Megalaspis faunas, is further shown by the recent discovery by Walcott[29] of *Ceratopyge canadensis* in the Lower Goodsir formation of British

[28] H. Loretz: Jahr. Preuss. Geol. Landesanst., 1881, p. 175.

[29] Cambrian Geology and Paleontology, vol. ii, No. 7, 1912. The correct generic determination of this trilobite has, however, been questioned.

Columbia (base of Ordovicic) with *Orthis mollinensis* Walcott, a form related to *O. salteri* Hall of the Ceratopyge limestone of Scandinavia, and by the fact that Megalaspis in America is practically confined to the early Ordovicic (Beekmantown) of the Pacific region (inclusive of the Rocky Mountains) of North and South America (two and four species respectively), though one species also occurs in the "erratics" in the Lèvis formation of Quebec and one is reported from the Richmond of Iowa.

Although Ceratopyge and Megalaspis are restricted to the Scandinavian-Russian region, other trilobites associated with them in the Norwegian region are widely distributed in the Atlantic province. These are Euloma, Niobe, Angelina, Asaphellus, Cheirurus, Cyclognathus, Parabolinella, Shumardia, Symphysurus, etcetera. Several of these are already found associated with Dictyonema in the Lower Tremadoc, while others characterize the Upper Tremadoc or the beds below the Phyllograptus shales. This trilobite fauna, designated by Brögger the Euloma-Niobe fauna, is also known from the Christiania region, Bavaria, southern France, Bohemia, Sardinia, and seems to be represented in eastern Canada. The presence of some of these genera in the Ceratopyge limestone of Westergotland (*Euloma ornatum* A., *Niobe insignis* Lns., *Symphysurus angustatus* Boeck, etcetera) suggests that they, like the Ceratopyge, are of North Pacific or Siberian origin. This may be true of some of the other trilobites as well, their distribution westward being more extensive than that of Ceratopyge. Some of them may have an Atlantic origin, but our present knowledge of their distribution does not permit us to form any more positive judgment in the matter.

It should also be recalled that another fauna, the typical Beekmantown fauna, existed at this time in the Champlain Valley, Newfoundland, and the north of Scotland, extending possibly to the Birikalk of Norway. There can be little doubt that this fauna had a distinct origin, since it is unknown from southern regions, or, for that matter, from any other portion of the Old World.

The following diagram represents the interrelation of the three faunas (figure 4).

Turning now to Division B II, the "Glaukonitkalk" of Fr. Schmidt (exclusive of the *Asaphus expansus* beds), we find that Lamansky has been able to recognize three distinct divisions, which he has designated from below upward B II α, B II β, and B II γ.

The first of these, B II α, is quarried on the Wolchow River near Saint Petersburg, under the name *Dikari*. The rock consists of limestone layers 13 to 27 cm. thick. These have a bright red, yellow, violet, or gray green color. The limestones have a thickness of 1.65 to 1.8 meters, but

the underlying green marly beds which form a transition to the Glauconite sand below (B I) also belong to this horizon. The fauna is especially characterized by *Megalaspis planilimbata* Ang. in the lower and *M. limbata* Sars. and Boeck, *M. polyphemus* Brögg., and *Asaphus priscus* Lamsk. in the upper part. Ptychopyge, Niobe, Ampyx, Illænus, and Cyrtometopis are also represented. Besides this there are a number of species of Orthis, many of them identical with or close mutations of the species found in the underlying B I β beds.

The second division, B II β, known locally as "Sheltjaki," consists of thin-bedded, less compact, mottled limestone with sporadic glauconite grains. Its thickness is 1.80 meters. It is especially characterized by *Asaphus bröggeri* Dalm. and *Onchometopus volborthi* F. S., and contains, besides two species of Megalaspis (*M. kolenki* F. S. and *M. hyorrhina*

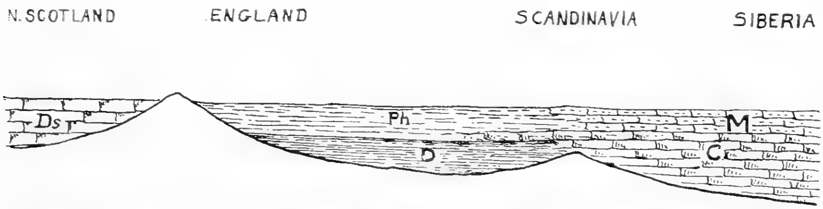

FIGURE 4.—*Ideal Section illustrating the Relationships of the several Types of Deposits in the north Scottish, Atlantic, and Siberian Provinces in Lower Ordovicic Time*

In the north Scottish region the Durness limestone facies (*Ds.*) with Beekmantown fossils occurs. In the central or English region (Atlantic province) graptolite shales predominate, the Dictyonema shales (*D*) being succeeded by the Phyllograptus shales (*Ph.*). In the eastern or Siberian region limestones predominate, with the Ceratopyge and earlier beds below (*C*), followed by the Megalaspis limestone (*M*).

F. S.), *Niobe lindströmi* F. S., *Nileus armadillo* var. *depressa* Sars. and Boeck, two species each of Cyrtometopus and of Illænus, and one each of Pterygometopus and Amphion. The generic relation of this trilobite fauna to that of the Ceratopyge horizon is evident, though the species are mostly distinct. Of the species of Orthis and Orthisina, some continue from the underlying beds, while all but one of the species of Porambonites found in B II β also occur in B II α, and all extend up into B II γ, but not above this horizon.

The third division, B II γ, consists of rather compact gray limestone, known locally as "Friese," and having a thickness of 2.40 to 2.70 meters. It is separated from the overlying B III α by a wavy surface above which glauconite abounds. This horizon contains a rich fauna in which *Asaphus lepidurus* and *Megalaspis gibba* are considered the leading types. Three other species of Megalaspis are found here, one of them continued from the bed beneath, as is also *Onchometopus volborthi* F. S., *Ptychopyge*

angustifrons Dalm., *Cyrtometopus clavifrons* Dalm., *Illænus centrotus* Dalm., and *Amphion brevicapitatus* Lamansky. Other species of these genera also occur. All of the brachiopods continue upward from the preceding bed or the one before it, and the same may be said of the crinoids, corals, and Bryozoa. On the whole, while all three divisions show relationship, B II β and γ are more closely related faunally, while B II α is closely bound to the preceding horizons of B I. There is, however, an absolute distinctness of species between horizons B II and B III, with the exception of the Bryozoa. Of the 31 trilobites of Division B II, only *Ptychopyge angustifrons* Dalm. is recorded from both B II and B III; but, as Lamansky points out, under this name are included many distinct mutations, which, when separated, would be found to be restricted to distinct horizons. None of the twenty brachiopods found in B II pass upward into B III, and the same is true of the 13 echinoderms and of the pteropods and cephalopods. Only among the Bryozoa seems there to be a continuance of species, not only between B II and B III, but also between B II and horizons above B III. Of the 12 species recorded by Bassler from B II, 7, or 58.33⅓ per cent, occur in B III or in C. Two of these range into the highest division of the Baltic series. Two species are American, found here in the Lower Trenton. Either sufficient care was not taken in the collection of the material on which Bassler based his determinations or the Bryozoa are not such good horizon-markers as has been assumed.[30]

The entire group B II is designated by Lamansky as the Megalaspis group,[31] while the succeeding division, B III, is designated the Asaphus group. This also consists of three divisions designated B III α, B III β, and B III γ, respectively, by Lamansky. The first is characterized by *Asaphus expansus*, *A. lamanskii*, etcetera; by species of Niobe, Illænus, Cyrtometopus, Metopias, and other trilobites. Among these, *Illænus esmarckii* Schloth. and *Cyrtometopus affinis* Ang., *Amphion fischeri* Eichw., and *Metopias pachyrrhina* Dalm. range through all these subdivisions.

B III α is also marked by the first appearance of *Orthis calligramma* Dalm., which ranges through the whole division and is wide-spread in the Upper Ordovicic of England (Caradocian), and the equivalent horizon

[30] See also Axel Borns' criticisms of Bassler's Bryozoa lists. Centralblatt für Min. Geol. u. Pal., 1913, p. 712. It should be remarked in justice to Bassler's work that the material on which he based his determinations was brought together by several collectors, and that he can not be held responsible for misplacement of horizons.

[31] Raymond has proposed the name *"Walchow formation"* for this division, but includes with it Division B I and Division B III α of Lamansky. This last is not justified, owing to the evidence of a break between B II γ and B III α, and especially because of the almost complete change of fauna as recorded by Lamansky.

in Galicia and elsewhere. In Sweden it occurs in the Lower Chasmops limestone of Dalecarlia. Another species of Orthis confined to B III α is *Orthis callactis* Dalman, which occurs in the Asaphus limestone of Dalecarlia. *Lycophoria nucella* Dalm. is another species appearing here for the first time and ranging through B III, and so is *Strophomena jentschi* Gay, important as characterizing the Asaphus limestones of Œland and the boulders of limestone conglomerate to be referred to later.

The second member of the Asaphus limestone, B III β, is a mottled yellowish to reddish limestone, with a thickness of about 3.5 meters. The fauna is not markedly distinct from that of B III α, but is especially characterized by *Asaphus raniceps* Dalm. Four species of Megalaspis occur here, including *M. acuticauda,* which also occurs in B III α, and has a related form in B II γ. *Megalaspis heros* Dalm. also occurs here, and *Asaphus expansus* Dalm. is continued upward from B III α. The

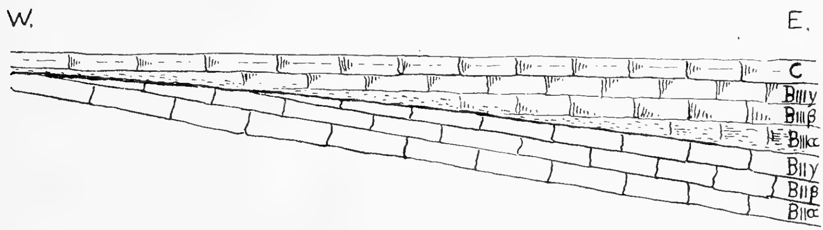

FIGURE 5.—*Diagram illustrating the westward Increase of the Hiatus between Divisions B II and B III in Esthonia*

(Modified after Lamansky)

horizon carries a thin layer of lenticles of brown iron oxide (Untere Linsenschicht) a short distance above the base, in which, according to Raymond, *Pliomera fischeri* and *Lycophoria nucella* are especially abundant.[32]

The upper division, B III γ, is a heavy bedded limestone, about 6 meters thick, and is especially characterized by *Asaphus eichwaldi* F. S. and *Ptychopyge* (*Pseudasaphus*) *globifrons* Eichw. This fauna differs more from the preceding two than do their faunas among themselves. Several of the trilobites, however, as well as a number of brachiopods, are common to all these divisions. The most marked character of this division is, however, the appearance of numerous Cephalopods of the genera Endoceras, Vaginoceras, Planctoceras, Estonioceras, and Cyrtoceras. The gastropods Raphistoma, Maclurea, and Salpingostoma also occur.

A second zone of phosphatic pebbles (Obere Linsenschicht) often separates this horizon from the succeeding Echinosphærites limestone, C 1.

[32] Raymond compares these "Linsen" to the disklike oolitic grains of the Clinton iron ore of North America. He places this and the succeeding Division B III γ in his *Kunda* formation, from which he, however, excludes Lamansky's Division B III α.

The fauna of this latter horizon in the Baltic Provinces is, according to Lamansky, very distinct, not a single species found in any member of Division B passing upward, while many new genera make their first appearance.

Physically the two divisions, B II and B III, are separated by a hiatus which shows an increasing magnitude westward (figure 5). This is indicated by the progressive failure westward of the upper members of B II and the lower members of B III, until near Baltic Port both series are chiefly represented by their extreme members. B II at this point shows a much eroded surface and is followed by a conglomerate and sandstone containing fragments of the underlying bed and resting variously on B II α, B II β, or more rarely on B II γ. The sandstone represents B III γ, so that B III β and B III α are wanting through overlap. Evidently after the deposition of the three members of B II an eastward retreat of the sea followed, resulting in the laying bare of the deposits which were then eroded. After this they were progressively covered again by the transgressing sea, with the successive deposition of the westward overlapping members of Division B III. Thus B III α fails in the vicinity of Saint Petersburg and B III β in the neighborhood of Reval, each in turn being overlapped by the succeeding formation. The Chasmops or Echinosphærites limestone alone is continuous and without marked lithic change over this area.

Eastward of Baltic Port the base of the upper series (B III γ) is a limestone with a basal phosphatic conglomerate formed of fragments of the underlying Megalaspis limestone. At Putilowo the Megalaspis beds still show marked erosion, followed by a glauconitic conglomerate, while beds with *Asaphus expansus* (B III α) begin to appear. Still farther east the surface of the underlying bed is smooth, and the contact is marked only by glauconite grains in the overlying bed. The glauconite grains above this contact show evidence of attrition, as do also the fossils found in B III α in this region, these being often strongly worn and frequently broken.

That the hiatus between B II and B III is greater than is indicated by the physical break described is evident from the complete change in fauna, and it is hardly to be questioned that, if proper exposures occurred farther east in Russia, not only would additional beds be found above B II γ—that is, below the break—but others below B III α—that is, above the break. I have elsewhere[33] correlated this progressive-transgressive movement with the one I had established in the North American

[33] Physical and Faunal Evolution of North America, etc. Journ. Geol. and Outlines of Geological History, edited by Willis & Salisbury, p. 65, 1910.

series between the Beekmantownian and Chazyan. The Megalaspis beds of the Baltic region, B II, thus correspond to the early Beekmantown of the Mohawk Valley and the Upper Mississippi, as is also shown by the intimate relation of the Megalaspis beds to the preceding basal Ordovicic Ceratopyge horizon. In the same manner they correspond to the Lower Magnesian series of the Upper Mississippi Valley, which is separated from the Upper Chazyan Stones River beds (*Plattville limestone*) by the St. Peter sandstone, shown by Berkey and myself to represent a continental deposit (chiefly eolian) formed during the long interval of exposure. This St. Peter hiatus, as we may designate it, is therefore recognizable on both sides of the Atlantic, and since it is also marked in the Rocky Mountain region (Harding sandstone horizon) and in Nevada (Eureka quartzite horizon), it must be regarded as indicating a universal compound eustatic movement, and should be shown in other parts of the world. The evidence for its existence in England and Bohemia will be considered later.

What the age of the Asaphus beds overlying the hiatus is, is less readily determined. Bassler, on paleontological grounds, correlates it with the Lowville; but he also places the Glauconite limestone in this horizon, which we have just shown to be of early Beekmantown age.[34] The exact equivalency can only be determined from the relationships shown in Scandinavia, though it may be well to call attention again to the appearance in this horizon of *Orthis calligramma*, a characteristic Caradocian brachiopod.

CORRELATION OF THE EAST BALTIC AND SCANDINAVIAN HORIZONS

Returning now to the Swedish occurrences of the Orthoceras limestone, which term, unlike its use in the East Baltic region, where it comprises only the Asaphus horizon, B III, includes in Sweden the Megalaspis beds (B II), we must first turn our attention again to the Westergotland sections and attempt to correlate the subdivisions there found with those of the East Baltic Provinces. It is evident that the Lower Red Orthoceras limestone with *Megalaspis limbata* corresponds to B II a of the Baltic region, while the Lower Chasmops limestone with *Echinosphærites aurantium* corresponds to C 1 of the Baltic Provinces. This leaves all of the higher Orthoceras limestone to be correlated with the intervening divisions. Incidentally, it may be recalled that the Limbata limestone is separated from the Ceratopyge beds by the Lower Didymograptus shale.

[34] Raymond, who designates the upper beds (B III β and B III γ) by the name of Kunda formation, makes them equivalent to the Upper Beekmantown of America. In this I strongly disagree with him. They are of late Chazyan, if not of younger, age.

with Tetragraptus, Didymograptus, and Phyllograptus (Lower Deepkill of America), and that this shale therefore replaces the Planilimbata limestone.

The Asaphus limestone immediately succeeding the Limbata limestone in Sweden is the equivalent of a part of B III of Esthonia; hence the zones B II β and B II γ are wanting in Westergotland, and the lower Middle Ordovicic hiatus (St. Peter hiatus) falls immediately above the Limbata beds. The fossils of the Asaphus limestone, which serve to correlate it with the East Baltic formations, are *Megalaspis heros* Dm., which occurs in the *raniceps* and *eichwaldi* zones (B III β and B III γ) of Russia, *Illænus esmarkii* Schloth, found in all three divisions of B III, and *Ampyx nasutus* Dm., which occurs in B III α and the lower and middle part of B III β. *Asaphus raniceps,* the zone fossil of B III β, is represented in the Asaphus limestone of the Kinnekulle by variety *maxima* Br.

From these considerations it would appear that the Asaphus limestone represents the middle and perhaps part of the upper division of the Russian Orthoceras limestone (B III β and B III γ a). The absence of *Asaphus expansus* certainly suggests the absence of the lower zone, B III α, though this seems to be represented in the Christiania region (Expansus shale) and in Dalarne, where it rests on the Limbata limestone.

That the line of division is not definitely drawn in the Kinnekulle region is shown by the occurrence within the Asaphus bed there of *Cyrtometopus clavifrons* Dal., a form characterizing all three members of Division B II in the South Baltic region. It is highly probable that the part in which this is found belongs to the Limbata limestone, the extent of which is thus equivalent to that of the Lower Red Orthoceras limestone as held by G. Holm.

The Gigas limestone of Westergotland may represent the upper part of B III γ or the lower part of C I α. This latter division includes the Platyurus limestone, as shown by the presence of *Asaphus platyurus* A., while the Chiron limestone, with *Illænus chiron* Hm., represents the horizon C I β of the East Baltic region. The succeeding Chasmops limestone probably represents the remainder of the Echinosphærites bed or C I γ of the Baltic region, and perhaps C II as well. It contains *Ampyx rostratus* Sars., which ranges from C I β to C II and *Echinosphærites aurantium* Gyllenh., which ranges through all divisions of C (Echinosphærites, Kuckers, and Ifter beds), and is reported from the Jewe and Wassalem beds (D I and D III) as well.

The Trinucleus shale following this series of limestones contains a fauna which has no representation in the East Baltic region, and the

same is true of the beds referred to the Brachiopod shale at the Kinnekulle. The abundance of Trinucleus, Staurocephalus, and Dionide in the former and of Dalmanites, Lichas, and Homalonotus in the latter, all genera absent or rare in the East Baltic regions, suggest Atlantic affinities. The same origin probably holds for the Graptolite fauna of the Upper Graptolite shale (Siluric).

In Östergotland, east of Lake Wettern, the Dictyonema shale has a thickness up to 3.5 meters, its base being everywhere a sandstone, which at Vestano is more than 2 meters thick. This has been regarded as the *Obolus* sandstone by Wiman, though the characteristic fossils have not been found in it.[35] The Ceratopyge limestone seems to be represented by a glauconitic marl. The Orthoceras limestone, quarried since the beginning of the nineteenth century, has furnished many of the types of trilobites described by Dalman and comprises in descending order:

Expansus limestone, greenish to red.
Gray limestone.
Heros limestone (with *Megalospis heros* A.).
Reddish limestone.
Planilimbata limestone.

Underlain by greenish marl and Dictyonema beds, as previously noted.

Megalaspis heros is characteristic of the Raniceps and Eichwaldi zones of the East Baltic region (B III β and B III γ), but has not been recorded from the Expansus zone. The reddish limestone is probably the Limbata limestone, and this would place the break between this bed and the Heros limestone. However, the occurrence of the Expansus limestone higher up suggests some irregularity of interpretation, unless the Heros limestone and the gray limestone above it constitute a part of the Expansus zone. The Orthoceras limestone is followed by the Chasmops limestone with its lower Echinosphærites division and the upper with *Chasmops macrourus* (Macrourus limestone), and then by Trinucleus shale and Brachiopod shale.

In Närke (Nerike), north of Lake Wettern, the break comes above the Planilimbata limestone, which rests on Shumardia shales (Ceratopyge horizon —). Beneath this is a glauconitic limestone with phosphatic nodules, which in turn overlies the Peltura zone of the Upper Cambric and cuts out the Dictyonema shales. The succeeding lower gray Orthoceras limestone appears to represent the raniceps horizon, B III β, the Expansus horizon being absent here.

[35] Moberg: Silurian of Sweden, p. 150.

LOWER ORDOVICIC OF DALARNE

This province shows several interesting developments of the earliest Ordovicic rocks, a part of which I was enabled to study under the guidance of Dr. Elsa Warburg and Prof. Carl Wiman, both of Upsala. Important sections have been worked out by G. Holm,[36] S. L. Tornquist (1883-1884), H. Hedström (1894), F. v. Huene (1904),[37] and Carl Wiman (1906). Marr[38] has also added some interesting facts regarding this district.

In the environs of Nittsjö, on the eastern end of Siljan See, some of the most complete sections are seen. These are best approached from the village of Rättvick, which lies on the shore of the lake, which is here

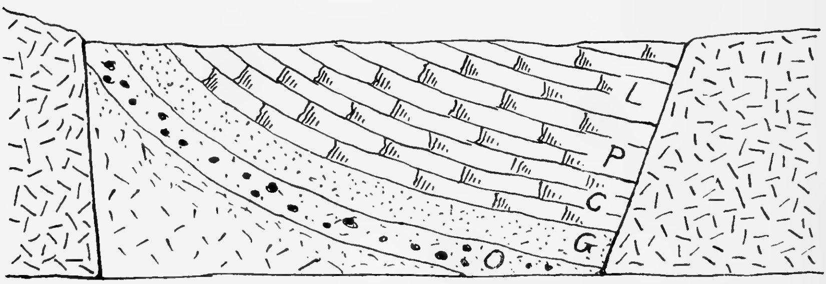

FIGURE 6.—*Section of the Lower Ordovicic Formations shown in the Railroad Cut near Sjurberg, in Dalarne, Sweden*

From a sketch by the **author.** **Paleozoics** are faulted into the granite mass, the fault block showing at the base **fresh granite**, which passes upward into decomposed granite. This is succeeded by the **Obolus** conglomerate (*O*), the Glauconitic sand (*G*), and the limestone comprising the Ceratopyge bed (*C*), the Planilimbata limestone (*P*), and the **Limbata limestone** (*L*).

skirted by the railroad. About 4.5 kilometers northwest of Rättvick station, by the road which parallels the railroad, and less than a kilometer beyond the little settlement of Sjurberg, there is found in the railroad cut an interesting section which is here reproduced.[39]

The top of the granite basement of the series consists of from 0.1 to 0.4 meters of weathered granitic material, which passes upward into an irregular bed of fine conglomerate, mostly with quartz pebbles and granite

[36] Ueber einige Trilobiten aus dem Phyllograptus Schiefe Dalekaliens. Bit. K. v. Akad. Handl., Stockholm, 1882, Bd. 6, No. 9.

[37] Centralblatt f. Min., etc., 1904, No. 15.

[38] J. E. Marr: On the Cambrian (Sedgw.) and Silurian rocks of Scandinavia. Quarterly Journal Geol. Soc., London, 1882, p. 315.

[39] H. Hedström: Geologiska notiser från Dalarne I. Stockholm, Geol. För. Förh., Bd. 16, 1894, pp. 585-593. Ibid., Till fråg·an om fosforitlagrans uppträdlandi och förekomst. ide geologiska formations. Ibid., Bd. 18, 1896, pp. 65-70.

Wiman: Om ceratopygeregionen inom Siljansiluren. Ibid., Bd. 28, p. 453.

And Warburg's Guide to Excursions, C_2C_5, 10th Intern. Geol. Cong. (No. 21), p. 3.

fragments, and contains the phosphatic fragments and entire shells of *Obolus apollinis* Eichw. and grains of phosphatic nodules. This is the Obolus conglomerate (Ungulite sandstone) found in many places at the base of the Ordovicic. It ranges in thickness from 0.15 to 0.80 meter and passes upward into a glauconitic sand of about 0.1 meter thickness, which also contains fragments of these shells, and which in turn is succeeded by gray, somewhat glauconitic limestone—the Ceratopyge bed. This is characterized by *Lycophoria lævis* Stolley, and in it I found a specimen of *Eorthis christianiæ*. Small fragments of Obolus still occur.

The Ceratopyge bed passes without break into the Planilimbata limestone, and this into the Limbata limestone, these being all of the same kind of calcareous sediment with the characters of a typical calcilutite. The scarcity of organisms in this rock suggests that it may be a comminuted algal deposit, though no trace of such is found. The section is terminated by a fault.

The Ordovicic succession of this region in its entirety is as follows, in descending order:

Leptæna limestone.

Hiatus—disconformity.

Trinucleus shale.

d. Red calcareous Trinucleus shales	15 m.
1. *Remopleurides dorsospinifer* Portl.	
2. *Prœtus brevifrons* Ang.	
3. *Agnostus trinodus* Salt.	
c. Gray limestone with fragments of fossils	5–9 m.
Trinucleus.	
Orthis.	
b. Black bituminous Trinucleus shale	6 m.
1. *Trinucleus seticornis* His.	
2. *Calymene trinucleina* Linrs.	
3. *Remopleurides radians* Barr.	
4. *Orthis argentea* His.	
5. *Leptana quinquecostata* McCoy.	
(Numbers 1, 3 are characteristic of Dd_5 of the Bohemian succession.)	
a. Masúre limestone or Knyckelkalk	9–15 m.
Gray, very hard, knobby limestone with calc spar veins. No fossils.	

Chasmops limestone.

b. Macrourus limestone and shale	9 m.
Chasmops maximus Schmidt.	
Illænus linnarssoni Holm.	
Ill. parvulus Holm.	
a. Cystidean limestone	15 m.
Chasmops oldeni Eichw.	

Leptæna convexa.
Platystrophia dorsata His.
Caryocystites granatum Gyllenh.
Echinosphærites aurantium Gyllenh.
Monticulipora petropolitana Pand.

Orthoceras limestone (restricted).

Ancistroceras limestone.................................... 5 m.
Illænus crassicauda Wahl.
Nileus armadillo Dalm.
Asaphus rusticus Tqt.

Chiron limestone.. 5 m.
Nileus armadillo Dalm.
Illænus chiron Holm.
Asaphus tecticaudatus.
Asaphus brachyrachis Remelé.
A. densistris Tqt.
Megalaspis formosa Tqt.
Endoceras bellemnitiforme Ho'm.

Platyurus limestone... 13 m.
Asaphus platyurus Ang.
Endoceras bellemnitiforme Holm.

Gigas limestone... 12 m.
Megalaspis gigas.

Asaphus limestone... 8 m.
Asaphus expansus Wahl.
A. vicarius Tqt.
Megalaspis polyphemus var. *tornquisti* Schmidt.
Illænus esmarki Schloth.
Nileus armadillo Dalm.
Orthis callactis Dalm.
Orthisina ascendens Pand.
Lycophoria nucella Dalm.
Bucania planorbiformis (Linns.)
Salpingostoma cristatum (Linns.)
Lytospira angelini Lindst.
Vaginoceras vaginatum (Schloth.)

Hiatus—disconformity.

Megalaspis limestone.

Limbata limestone... 3. m.+
Megalaspis limbata Boeck.
Niobe læviceps Dalm.
Nileus armadillo Dalm.

Planilimbata limestone...................................... 3. m.+
Megalaspis planilimbata Ang.

Ceratopyge limestone.

Limestone .... 0.14–0.16 m.
Obolus fragments.
Lycophoria lævis Stolley.
Eorthis christianiæ.

Glauconite sand.. 0.1 m.
Obolus conglomerate..................................... 0.15–0.80 m.
Obolus apollinis Eichw.
Hiatus—unconformity.
Basement beds.
Weathered granite.................................... 0.1 to 0.4 m.
Fresh granite.

The beds above the Megalaspis limestone, or the divisions of the Orthoceras limestone in the restricted sense, are well exposed on the shore of the lake just beyond this cutting, and here a good collection of the typical fossils, especially the Orthoceracones, may be obtained. The lowest of these beds, and the one directly succeeding the Limbata limestone, wherever this is found in contact, is the Asaphus limestone with *A. expansus* Wahl, *Vaginoceras vaginatum,* and the other species noted above. Most of these species are also found in the Esthonian region, where they are confined to B III and higher beds. Since so many of them are characteristic of B III α, the *Expansus limestone,* and since *Asaphus expansus* also occurs in this limestone of Siljan Lake, it is evident that the series begins with that division. Thus the divisions B II β and B II γ found in the Russo-German Baltic provinces are omitted here, and the hiatus in Dalarne falls above the *Megalaspis limbata* bed. The total thickness of the Asaphus limestone is about 8 meters, and it is succeeded by the limestone with *Megalaspis gigas* (12 meters) and the higher beds. These higher beds are exposed in a more or less continuous section in the vicinity of Nittsjö, something over a kilometer northeast of the railroad cut just described.

An interesting section occurs at Skattungbyn, near the northern end of Siljan Lake, and about 40 kilometers northwest of Rättvick.[40] This we did not visit, but it is significant in our discussion. The base of the section is a layer of green limestone a foot in thickness and resting directly on porphyry, of which it incloses angular fragments. This is followed by green Phyllograptus shales with layers of limestone. The shales contain *Tetragraptus serra* Brongn., *T. quadribrachiatus* Hall, *T. curvatus* Tqt., *Phyllograptus densus* Tqt., *Dichograptus octobrobrachiatus* Hall, *Didymograptus minutus* Tqt., *D. gracilis* Tqt., *D. decens* Tqt., and some brachiopoda. From the inclosed limestone layers Holm has obtained *Pliomera tornquisti* Holm, *Megalaspides dalecarlica* Holm, *Niobe læviceps* Dalm., *Ampyx pater* Holm, *Agnostus törnquisti* Holm.[41]

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[40] Törnquist: Öfversigt öfver bergbyg-gnaden inom Siljasområdet i Dalarne. S. G. U., Ser. C, No. 57; Warburg., E. Guide, pp. 5-6.

[41] Holm: Ueber einige Trilobiten aus dem Phyllograptuschiefer Dalekarliens, Bih. K. V. Akad. Handl., Stockholm, 1882, vol. 6, No. 9.

The graptolites are evidently the equivalent of the Lower Arenig of Britain and of the Lower Deepkill of America. As already noted, *Megalaspides delecarlica* is a close relative of, if not identical with, *M. schmidti*, from the upper part of B 1 β of the East Baltic region. *Niobe læviceps* also occurs in East Baltica in B I β and B II α. The basal limestone of Skattungbyn is regarded by Wiman as the Ceratopyge limestone.

ORDOVICIC OF JÄMTLAND

Strangely enough, Phyllograptus shale is present in Jämtland, though unrepresented in the more southerly regions. This seems to be an expansion from the Christiania region passing to the west of the Nittsjö region in Dalarne (eastern end of Siljan See), but including the northern end of the Dalarne Paleozoic province (Skattungbyn). The shale has already been referred to as carrying intercalated limestone bands with the Megalaspides fauna, and thus serving to bring the two facies from east and west together. Moberg has found a representative of the Ceratopyge limestone as a thin bed overlying the Upper Cambric in some sections. In this he found *Eorthis christianiæ* Kjerulf, *Niobe læviceps* Ang., and *Cyrtometopus* cf. *foveolatus* Ang. In another bed he found *Niobe insignis* Linrs. and *Megalaspis stenorhachis* Ang.?

The Orthoceras limestone of Jämtland is particularly well developed in the country north of Brunflo, and between that place and Östersund. It has much the character which it possesses in Westergotland, that is to say, it represents both the lower *Megalaspis limbata* division, which belongs to the Lower Ordovicic, and the *Asaphus-Gigas-Platyurus* division, which belongs to the Upper Ordovicic. Here, then, as in Dalarne and in Westergotland, the Orthoceras limestone includes within itself the hiatus which represents practically the whole of the Middle Ordovicic (Chazyan of the American scale) and a part of the Lower Ordovicic as well. In thickness the limestone varies from 37 cm. in the Brunflo region to 90 meters in Klöfstjo and Skalängen.[42]

A peculiar development of the basal part of the Ordovicic is found in the Locknesjö Lake region of Jämtland and has been described in detail by Wiman.[43] Resting directly on the granitic basement is a breccia and residual arkose derived from the decomposition of the underlying rock. This is locally known as "Loftar stone," and it is succeeded by the Orthoceras limestone, a part of which it may actually replace. The following section (figure 7), given by Wiman, shows the relation of these beds.

[42] Moberg: "Silurian of Sweden," p. 146.

[43] Carl Wiman: Ueber die Silurformation in Jämtland. Bull. Geol. Institute, University Upsala, vol. iv, pt. 2, 1899.

The restoration in terms of original sedimentation, as I conceive it, is shown in the second diagram (figure 8).

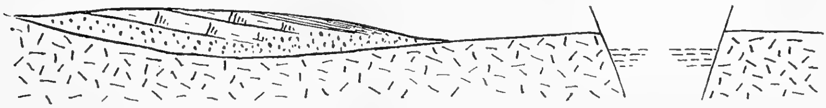

FIGURE 7.—*Section of Crystallines and Early Paleozoics in the Locknesjö Lake Region, Jämtland, Sweden*

Showing the "Loftar stone" resting on the crystallines and followed by the Orthoceras limestone. (After Wiman)

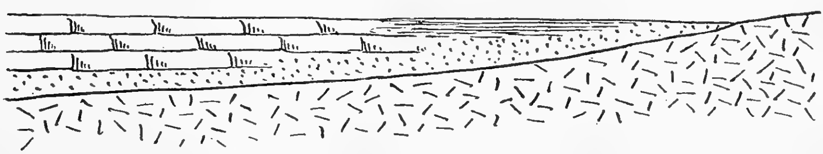

FIGURE 8.—*Ideal Section showing Relationship of Beds of preceding Section before Deformation and Erosion*

LOWER ORDOVICIC OF THE CHRISTIANIA REGION

This region is nearer the meeting ground of the Atlantic and Siberian faunas, and hence we find a more pronounced representation of both. The section of the Ordovicic strata comprises the following:

Superformation—Etage 6. Siluric.

Ordovicic.

Etage 5 b.	With *Meristella crassa.*	
	Hiatus and disconformity.	
		Feet
Etage 5 a.	Calcareous sandstone.	
	5 a and b range from	150–370
Etage 4.	Shales and marls with Trinucleus, Chasmops, etcetera	700
Etage 3 c λ.	Orthoclase limestone	8–13
Etage 3 c β.	Expansus shale	10–15
	Hiatus—disconformity.	
Etage 3 c α.	Megalaspis limestone	3–4
Etage 3 b.	Phyllograptus shale	8–80
Etage 3 a λ.	Ceratopyge limestone	3–5
Etage 3 a β.	Ceratopyge shale	3–23
Etage 3 a α.	Symphysurus shale and limestone	1–20
	Hiatus—disconformity.	

Upper Cambric.

The Phyllograptus shale here represents the Planilimbata limestone. It is followed by the limestones with *Megalaspis limbata* (3 c α),[44] and

[44] The notation here is distinct from that used in Esthonia.

these by shales with *Asaphus expansus* (3 c β), above which lie in turn the Gigas and Platyurus beds (3 c γ) with *Megalaspis gigas* and *Asaphus platyurus.* The succession is thus as in Dalarne, with the hiatus between the Limbata and Expansus horizons, the chief difference being the replacement of the Planilimbata limestone by Phyllograptus shale and the greater development of the Ceratopyge beds.

ORDOVICIC OF ŒLAND

This island, situated off the southeastern coast of Sweden, shows certain significant sections which are corroborative of the correctness of the general thesis so far developed. The Cambric, well developed in its middle facies, is disconformably succeeded by the Obolus conglomerate, which rests on successively lower members of the Middle Cambric from south to north. This conglomerate contains angular fragments of the underlying Cambric beds, those in the northern region carrying the remains of *Paradoxides tessini.* The cement of the conglomerate contains *Dictyonema flabelliforme, Obolus* cf. *apollinus,* Olenus sp. *Agnostus pisiformis* and var. *obesus.* The Dictyonema is found only in the cement of the upper part of the conglomerate, which is generally succeeded conformably by Dictyonema shale, except where this species occurs in the cement of the conglomerate. This suggests that the two formations are more or less contemporaneous, the Obolus belonging to the eastern fauna and the Dictyonema to the western.

The Ceratopyge limestone rests conformably on the Dictyonema shale when this is present, its base, as at Ottenby, on the south end of the island, being sometimes represented by an alum shale (Ceratopyge shale) carrying *Shumardia pusilla* Sars. and *Ceratopyge forficula* Sars., similar to the Christiania development. The Ceratopyge limestone is succeeded conformably by the Planilimbata and Limbata limestones with their characteristic fossils as elsewhere developed. This in turn is succeeded by the Asaphus limestone, which is divided into a lower and an upper bed, separated by a zone of limestone crowded with the globular cystoid *Sphæronis* (*Holocystites*) *pomum* Gyllenh. The lower bed seems to be identical with the Asaphus limestone of the mainland, but *Asaphus expansus* has not been found in it. It contains, however, *Strophomena jentschi* Gagel at several places in northern Œland. In the same rock Holm is reported to have found a specimen of *Didymograptus* (*Isograptus*) *gibberulus* (*I. caduceus* Salter). This is an Arenig species, while *Strophomena jentschi* suggests Upper Ordovicic affinities. If the latter is correct, then the break in the series comes here, as elsewhere in Sweden, above the *M. limbata* limestone, the next succeeding bed being

probably the equivalent of B III β of the East Baltic region. The succeeding beds of Œland, from the Gigas to the Ancistroceras limestone, are similar to those of Dalarne and elsewhere.

The S. jentschi conglomerate.—As having an important bearing on the correlation of the Œland strata, there should be mentioned the occurrence in parts of Sweden and elsewhere of a conglomerate in the matrix of which *Strophomena jentschi* is a characteristic fossil.[45] The cement "is a light gray limestone, partly coarsely crystalline, partly compact, more rarely merging into a coarse-grained, glauconitic sandstone with calcareous spar cement."[46] Besides *S. jentschi* it contains *Platystrophia biforata* Schloth, *Illænus* sp., and others. This would indicate the Caradoc or Trenton age of this bed, as well as that of the Lower Asaphus limestone of Œland. The pebbles of the conglomerate are phosphorites and phosphoritic sandstones, the former bearing fossils of Upper Cambric age. "The conglomerate was first observed by Gagel (1890) as boulders [*Geschiebe*] in East Prussia, but its age could not be determined until J. G. Anderson had proved the occurrence of *S. jentschi* in the Lower Asaphus limestone . . . in northern Œland."[47] Subsequently the boulders were found at Stonåsa, in Œland, at Gotland, and elsewhere, thus showing a wide distribution. The home of the conglomerate is probably in northern Sweden, where it rested on Cambric strata, and it probably indicates the wide-spread overlap of the readvancing Upper Ordovicic sea over the eroded surface exposed by the preceding retreat. As this seems the only rational explanation, and as the associated fossils in the matrix stamp the conglomerate as Upper Ordovicic, the finding of *Didymograptus caduceus* in the bed with *S. jentschi* on Œland (if this did not come from a lower layer) suggests that this may be a case of inclosure of Arenig from an underlying source comparable to the inclosure of fragments with Cambric fossils in the *S. jentschi* conglomerate.

ORDOVICIC OF SCANIA

General discussion.—This region, in the extreme southern end of Sweden, is of interest because it shows the dominance of the Graptolite facies of the Ordovicic series. There is some difference of development between the eastern and western sections, as brought out by Moberg's detailed studies. It was my good fortune to spend the better part of a week in the study of these Scanian deposits under the able and enthusiastic guidance of the late Prof. J. C. Moberg, of Lund University, whose

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[45] J. G. Anderson, 1896: Ueber die Cambrische und Silurische phosphorit-führende Gesteine aus Schweden; also Moberg: "The Silurian of Sweden," p. 108.

[46] Moberg: Loc. cit.

[47] Moberg: Loc. cit., p. 119.

profound knowledge of the region made him the leading authority in this field, and I wish to record here his zeal and eagerness in guiding us, so that we should miss none of the important localities of the district. His untimely death is a hard blow to Swedish science and is regretted in America as well as in his native land. In the following descriptions I follow him closely, with only occasional additions of my own; for the interpretations, however, I alone am responsible.

East Scania.—The eastern region is shown especially well in the sections between Tommarp and Jerrestadt, the latter lying about 3 kilometers east of the former. Some of the best exposures are found along the creek passing through the two localities, but only in the more westerly area (Tommarp) are the exposures continuous. In the Jerrestadt region we found only scattered exposures, and some of the beds we could study only after removing the surface soil. Professor Moberg's intimate knowledge of the region here stood us in good stead, but we were not certain that the succession might not be interfered with by unrecognized faults, in which this entire region abounds. At Tommarp, however, the succession was clear and faults were eliminated.

The Dictyonema shales are shown in the exposure near Jerrestadt at several places and appear to lie directly on the Acerocare beds of the Upper Cambric, though the contact is not shown. In the lower beds *Dictyonema flabelliforme* Eichw. occurs, and higher up *Clonograptus tenellus* var. *callavei* Lapw. and var. *hians* Mbg., as well as *Bryograptus hunnebergensis* Mbg., while in the highest part occurs the subzone with *D. flabelliforme* var. *norwegica* Kjerulf and *Bryograptus kjerulfi* Lpw. These beds are succeeded by alum shales carrying *Ceratiocaris scanicus* Westergard, and believed to be the equivalent of the Shumardia zone of the Ceratopyge shales, while the limestone immediately succeeding them is classed by Moberg as Ceratopyge limestone, though typical fossils have not been found in it. Above this follow the Lower Didymograptus shales, the zone with *Didymograptus balticus, D. geometricus* Törnq., *D. constrictus* Hall, *Tetragr. quadribrachiatus,* and *Schizograptus rotans* Törnq., following directly on the supposed Ceratopyge limestone. Then follow Törnquist's zones *c* with *Phyllograptus densus* Törnq. (= *P. angustifolius* Hall) and *d* with *Isograptus gibberrulus* Nich. (*Didymograptus caduceus*). All of these represent Lower Arenig. They are succeeded by Orthoceras limestone, apparently representing the *Megalaspis limbata* beds, but this is not definitely ascertained. Somewhat higher, after a covered interval, occur shales with *Dicranograptus clingani* Carr., *C. bicornis* Hall, *Diplograptus quadrimucronatus* var. *spiniger* Lapw., *Lasiograptus margaritatus* Lapw., and *Corynoides calicularis* Nich. Higher

up occur *Diplograptus foliaceus* var. *calcaratus* Lapw. and *Dicellograptus forchhammeri* Gein. We have thus the Dicellograptus or Normanskill shales following almost directly on beds of Deepkill (Arenig) age, as in eastern North America, but with a thin limestone, probably representing the *Megalaspis limbata* beds, intervening. If this limestone is correctly identified, the break in the series comes above it, this break representing the greater part of the Arenig and of the Lower Llandeilo, or, in American terms, most of the Beekmantown and the whole of the Chazy.

A nearly continuous section is exposed in the stream bank south of Tommarp, which I here reproduce from my notes (figure 9). The beds dip at a gentle angle to the north, this dip being lowest at the southern end of the section. Here a quarry has been opened in the "Orthoceras limestone," which here represents the *Megalaspis limbata* limestone. The

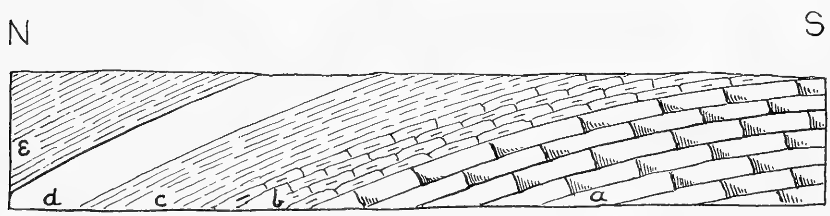

FIGURE 9.—*Section in the Stream Bank south of Tommarp, Scania, in southern Sweden*
a, Megalaspis limbata limestone; *b, Trinucleus coscinorhinus* beds; *c,* black shale with *Dicranograptus clingani; d,* covered; *e,* Trinucleus shale

limestone is in thin layers with shaly partings, the whole dipping about 20° to the north. Fossils are scarce, but I succeeded in finding a specimen of the pygidium of *Megalaspis limbata.* This limestone is followed by thin-bedded, dark, mainly black, fine-grained calcarenites, from which *Trinucleus coscinorhinus* Ang. and some other fossils have been reported. We, however, did not succeed in finding any of these.

Overlying this limestone are dark shales with *Dicranograptus clingani,* from which we also obtained some small brachiopods. After a covered interval, which may represent the zone of *Pleurograptus linearis* Carr. which we saw at Jerrestadt, a similar black shale with thin limestone beds completes the section. This is the zone of Trinucleus, the base of which is marked by a layer of iron pyrite concretions.

In spite of the good exposures (for Scania) of these beds, it was not possible for me to obtain any satisfactory physical evidence of the break in this section. It is perfectly clear that the break exists, since all the representatives of the later Arenig and early Llandeilo are absent. Even if the zones are represented in western Scania, a number are wanting here, these being, in ascending order, the zones of *Phyllogr. typus* and *Didy-*

mogr. geminus of the Upper Didymograptus shales, and the zones of *Glossograptus hincksi,* of *Diplogr. linnarssoni,* of *Diplogr. putillus,* and of *Nemagraptus gracilis,* or the whole of the Middle Dicellograptus shales, regarded by Moberg as the equivalent of the Chasmops beds of more northerly localities in Sweden. The zone with *Trinucleus coscinorhinus* is placed by Moberg below that of *Phyllograptus typus* from the relations believed to exist in West Scania. If this is the case, the break in the series comes above these limestones, and it must be confessed that the field indications seem to favor this, the contact between the shales and the limestone appearing a more likely place for a disconformity than between the two limestones. It must be remembered, however, that the position of the *Trinucleus coscinorhinus* limestone below the Phyllograptus shale in West Scania is by no means positively established, and that Tullberg has found *Ampyx rostratus* in the *T. coscinorhinus* zone, which he therefore regards as belonging to the horizon of the Chasmops limestone.

West Scania.—Turning now to West Scania, we find the best exposures of the Lower Ordovicic strata in the Fogelsång and Röstångo areas. The lower beds are seen only in the Fogelsång region, some 7-8 kilometers east of Lund. Here, too, the exposures are in a measure unsatisfactory, the only natural outcrops being along the Sularpsbäck and the Fogelsångbäck. By digging, however, in the banks along the streams and elsewhere, access was obtained to the underlying shales. Moreover, contacts between the several zones are among the rarities, and thus an element of doubt as to the absoluteness of the succession, made out by the workers in this field, must always remain.

The general development of the Ordovicic is almost exclusively in a shaly phase and the Atlantic graptolite fauna furnishes the dominant organic expression.

The lower zone of the Dictyonema beds with *D. flabelliforme* is seen only in the eastern end in the bed of the Sularps-bäcken south of the hamlet of Mejeri. The beds here include some thin calcareous layers, but they are not seen in contact with the higher beds. The two succeeding zones of the Dictyonema shale, that with *Clonograptus tenellus* and that with *Bryograptus kjerulfi,* are seen only on the Fogelsångbäck, especially near its junction with the Sularps-bäck. The outcrops are, however, discontinuous.

In the banks of the Fogelsångbäck, near the village of that name, digging reveals the upper beds of the Dictyonema zone, and here it is found in contact with the Ceratopyge limestone, both the lower or Shumardia zone and the Ceratopyge limestone proper being represented in

slight thickness. The continuity of the section is interfered with by a diabase dike. Close to this are the strongly metamorphosed Lower Didymograptus beds, with characteristic fossils still recognizable. This same zone appears again farther north on the banks of the Fogelsång brook, where it carries *Phyllograptus cor* Strandmark. These beds are described by Moberg as lying partly under (in the bed of the stream) and partly over (in the E. banks) the Orthoceras limestone. The "Orthoceras limestone" is shown in an old quarry near the brook; the west wall of this quarry shows the lower part of the Upper Didymograptus bed, the zone of *Phyllograptus* cf. *typus* overlying the Orthoceras limestone.[48] "At the bottom of the most southerly limestone quarry, . . . on the occasion when it was pumped dry, a slaty limestone was found, rich in trilobites, among which may be mentioned *Trinucleus coscinorhinus* Ang. and *Aeglina umbonata* (Ang.)." This exposure was not accessible during our visit. It is clear that there is some complication and confusion here, though it would appear that the *Trinucleus coscinorhinus* beds are included in or represented by the whole of the Orthoceras limestone, and that the Upper Didymograptus beds overlie this limestone. If this relation is normal and not due to faulting, it settles the position of the *Trinucleus coscinorhinus* beds as definitely *below* the break.

The Upper Didymograptus beds are well shown in a steep bank on the south side of the Sularp River, just above the mouth of the Fogelsång creek. Both the lower division with *Phyllograptus* cf. *typus* Hall and the upper or Geminus division with *Lonchograptus ovatus* Tull. are here shown, but no higher beds. These beds are also seen farther down the Sularp River at several localities, both in the bed and bank and on the Fogelsång, but as isolated outcrops which show no relation to higher or lower beds. At Sandby West Mills, about 500 meters above the mouth of the Fogelsång, the Lower Dictyonema beds are exposed not far from the Geminus beds, the former being seen in a ditch close to the north bank, the latter in the river bed and in the south bank. A short distance to the west Middle Dicellograptus shales, with *Orthis* (zone of *Ampyx rostratus* Sars. and *Calymene dilata* Tullb. of the Chasmops beds) appear, being brought next to the Geminus beds either by a fault or by the cutting out of the Lower Dicellograptus beds in this region, and an amplification of the hiatus which separates the Lower and Middle Ordovicic series. The Orthis shales are limited above by a diabase dike, 23 meters thick, which has burnt the shales white at this contact.

The Lower Dicellograptus beds are exposed at a number of localities on the Sularp River, both above and below the mouth of the Fogelsång.

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[48] Moberg: Guide, p. 26.

The best exposures are in the south bank of the river, from 500 to 600 meters below the mouth of the Fogelsång. Here the lowest zone of the region with *Glossograptus hincksi* Hopk. is seen, but not in contact with any lower formation. A hundred meters or more upstream, however, occurs an outcrop of the Geminus bed of the Upper Didymograptus shales. Since no other formations falling between these two are known in this region, the hiatus (St. Peter hiatus of American nomenclature) occurs in this interval. The lowest zone of the next higher series—that is, that of *Climacograptus rugosus* Tull. (= zone of *Dicranograptus clingani* Carr.) or the Lower Hartfell—is shown in the river bed only a short distance below this.

In the Röstanga district, on the north border of the Ordovicic-Siluric zone of West Scania (38 kilometers north from Lund), we meet with other exposures of these strata, though the lower beds of the Ordovicic are not seen. We did not visit the sections, but they have been fully described both by Tullberg (1883) and by Moberg. There seems to be some confusion regarding the interpretation of the lower beds, but the Orthoceras limestone of this section probably lies above the horizon of the Upper Didymograptus shales instead of below it. The two are not found in the same section, and this interpretation is based purely on paleontologic evidence, the stratigraphic evidence at first sight being against this.

The Orthoceras limestone is seen only in the Kvarnbäcken (Mill Brook), where it forms an isolated outcrop of black, hard, often crystalline limestones, alternating with lighter gray beds, exposed in the bed of the stream and dipping about 45° south. It has yielded a number of fossils; those reported by Tullberg and Moberg being: 1, *Asaphus acuminatus* Ang.; 2, *Æglina umbonata* (Ang.); 3, *Illænus esmarki* Schloth; 4, *Ampyx carinatus* (Ang.) Linss.; 5, *Niobe emarginula* Ang., and species of Ptychopyge, Trinucleus, and Orthis, as well as a Cystid. As Moberg remarks: "The limestone belongs with certainty to the upper part of the Scanian *Orthoceras* limestone (Asaphus beds)" (Guide, page 80). Compared with the Esthonian development, we find that number 3 of the above list characterizes all three divisions of B III, while number 5 is characteristic of B III α and B III β. In Dalarne and Westergotland *Illænus esmarki* occurs in the Asaphus limestone above the Limbata beds and, as I have shown, above the hiatus. By these standards, then, the Orthoceras limestone of Röstanga belongs to the upper part of the Middle Ordovicic, representing probably a part of the Lower Dicellograptus horizon. In the Mill Brook it is followed, after an interval of 400 meters, by hard Orthis shales with *Calymene dilatata* Tull., *Ampyx rostratus*

Sars., and *Orthis argentea* His. These represent the Chasmops horizon of the Swedish succession. Between these two outcrops Tullberg records shales with *Climacograptus rugosus* Tull. and *Cl.* cf. *cœlatus* Lapw. (that is, zone of *Dicranograptus clingani* Carr.), but these have not been found by later observers. In any case the beds recorded above the Orthoceras limestone in this brook belong to the Lower Hartfell horizon or the Middle Dicellograptus beds of Scania.

The Lower Dicellograptus shales are exposed in the Kyrkbäcken (Church Brook) about 500 meters east of the Orthoceras limestone outcrop above mentioned. They dip here at an angle of 40° south, with a strike of north 80° east, which would bring them, as well as the underlying Upper Didymograptus beds, *above* the Orthoceras limestone and below the Orthis shales of the Mill Brook section. The section is apparently a continuous one, the Upper Didymograptus shales with *D. geminus* being succeeded by the Lower Dicellograptus shales with *Climacograptus scharenbergi* Lapw., *Diplograptus teretiusculus* His., *Dicellograptus moffatensis* Carr., *Dicellograptus sextans* Hall, *Glossograptus* sp. *Corynoides calicularis* Nich., and *Primitia strangulata* Salter; also the trilobite *Robergia microphthalmus* (Linrs.). Since it is not likely that the Orthoceras limestone dies out in so short a distance, it must be cut out by a fault in the present section, where the Brachiopod shales (uppermost Ordovicic) come in after only a short interval, though some of the intervening Ordovicic beds are faulted in again beyond this point.

Tosterup.—The estate of Tosterup lies in the southeastern part of the Scanian Paleozoic belt, about 12 kilometers north-northeast of Ystad. The base of the Ordovicic is here the Dictyonema shales which succeed the Peltura zone of the Upper Cambric. No representative of the Ceratopyge beds is found in this region which corresponds thus essentially to the development at Jerrestadt-Tommarp, in East Scania. The Lower Didymograptus shales are poorly exposed, but seem to be conformably succeeded by Orthoceras limestone, which here, as at Tommarp, belongs to the lower division. In it have been found *Nileus armadillo* Dalm., *Megalaspis* (*planilimbata* Ang.?), Agnostus sp., and Orthoceras sp. That higher members of the Orthoceras limestone series may be present is indicated by the fact that Tullberg lists from this rock *Symphysurus palpebrosus* Dalm., *Cheirurus clavifrons* Ang., and *Illænus esmarki* Schloth, species occurring in the Upper Orthoceras or Asaphus limestone of Westergotland and elsewhere.[49] Beds believed to be those of the *Trinucleus coscinorhinus* zone with *Ampyx rostratus* have been reported above the

[49] *Symphysurus palpebrosus* occurs, however, in the Orthoceras limestone of Bornholm with *Megalaspis limbata*.

Orthoceras limestone, while the next higher zone is that of *Dicranograptus clingani* Carr. Here occur, besides the above, *Dicellograptus forchhammeri* Gein., *Climacograptus bicornis* Hall, and *Diplograptus foliaceus* Murch. The evidence from this section would seem to place the *Trinucleus coscinorhinus* zone above the break.

ORDOVICIC OF BORNHOLM [50]

This island forms the southeastern extension of the rock series exposed in Scania. It shows a large area of pre-Cambric rocks on the northeast, and an area of older Paleozoics on the south, and of Jurassic and younger strata in the west. As in Scania, there are numerous dislocations which complicate the succession.

The series begins with the basal arkosic Nexö sandstone, 60 meters in thickness, which corresponds to the Fucoidal sandstone of Sweden. This is conformably succeeded by a green graywacke shale consisting of alternating glauconitic clay shales and sandy shales with phosphate concretions and occasional thin limestones, the total having a thickness of 57 meters. Only *Hyolithes* (several species) and *Torellella lævigata* Linnrs. have been found so far. This, with the basal sandstone, represents a part of the Lower Cambric. The upper part of the series is arenaceous and it is disconformably succeeded by the *Paradoxides tessini* zone of the Middle Cambric, the lower beds of which contain, according to Grönwall, worn fragments of the underlying sandstone. The hiatus here represents the lower part of the Middle Cambric below the Tessini zone. The total thickness of the Middle Cambric, which consists mainly of alum shales, is 4 meters, and it passes conformably into the Upper Cambric Olenus beds, all of the higher Middle Cambric zones being represented. These Olenus shales with the typical Swedish Upper Cambric fauna are 15 meters thick. They are followed, apparently without break, by the Dictyonema shales, with a thickness of 5 meters, which, however, appear to represent only a part of the Dictyonema series. The Bryograptus and Tetragraptus zones are absent, the Orthoceras limestone following directly on the Dictyonema shale, with a thickness of 4 meters. The base of this formation consists of a thin, dark glauconitic limestone layer with much pyrite and numerous phosphatic nodules containing sponge spicules. Desiccation fissures are represented by their ridgelike fillings. The main part of the Orthoceras limestones consists of gray, somewhat nodular, limestone with 10 to 15 per cent clay. It contains numerous trilobites, among them *Megalaspis limbata* Buch., *Ptychopyge applanata* Ang., *Symphysurus*

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[50] In this section I rely entirely on Ussing, Handb. d. Reg. Geol., Bd. I, Abt. 2, Dänemark, 1910, as I have not visited this island.

palpebrosus Dalm., and *Nileus armadillo* Dalm. The formations thus represent the *M. limbata* horizon, but whether the *M. planilimbata* bed is represented in the lower part of the limestone or whether this and the Ceratopyge limestones are wholly wanting does not yet appear.

The limestone is succeeded by the Dicranograptus shale of the lower Upper Ordovicic, corresponding essentially to the Lower Hartfell shales of Scotland. There is thus a pronounced hiatus here, representing the Middle and Upper Arenig and the whole of the Llandeilo. Three zones are represented in the bituminous shales of this series. These are:

3. Zone with *Climacograptus styloides* Lapw.
2. Zone with *Dicranograptus clingani* Carr.
1. Zone with *Climacograptus vasæ* Tullb.

The lowest or oldest of these zones is not known in Scania, where the upper series begins with the zone of *Dicranograptus clingani* Carr. This lower zone, however, corresponds, according to Tullberg, to the zone with *Climacograptus wilsoni* Lapw. in Scotland.

There is thus clearly indicated a general overlap of the advancing Upper Ordovicic series over Sweden, though this was a very irregular one, some portions of Sweden becoming submerged before others.

Summary of the Early Ordovicic Sections

We may now summarize the early Ordovicic sections and deduce from them the sequence of events. Throughout most of western Europe the basal Ordovicic beds lie with a greater or less hiatus on the Upper Cambric or older formations down to the Archean complex. This marks a wide-spread transgression which was inaugurated with the beginning of Ordovicic time, following a previous partial withdrawal of the sea. In the English area alone the sedimentation seems to have been continuous, the Upper Cambric beds being conformably succeeded by the Tremadoc. But even here there may be proved a hiatus by future investigations.

Two main areas of sedimentation are recognizable—the Baltic and the Mediterranean. These were both open to the Atlantic of that period, but were themselves separated by the Old land of Armorica, which extended between them as a peninsula; while the southern or Mediterranean region seems to have been merely an embayment of the Atlantic, the Baltic was for part of the time at least a channel, connecting the Atlantic with the sea then covering part of Siberia.

A third center of deposition in Europe was the North Scottish one and its possible extension in the western Scandinavian region. This district appears to have been entirely separated from the Atlantic Ocean by the

old Caledonian land-mass which extended across the Atlantic to Newfoundland.

The sections discussed clearly indicate that the early Ordovicic transgression of the sea marked an eastward advance of the Atlantic waters along both channels, and with this also a lateral spreading and inundation of the low shores of the bounding lands, namely, Caledonia on the north, Armorica in the center, and probably North Africa on the south, though satisfactory sections of the African region are not available. In the Baltic region the Siberian Sea also transgressed from the northeast, and so a commingling of the Ceratopyge fauna from that region and of the Dictyonema fauna from the Atlantic region took place. The Atlantic fauna seems to have advanced eastward earlier—no doubt owing to the mud deposits which kept out the purer water fauna from the east. Thus when the Ceratopyge fauna in turn advanced with the clearing of the waters, the beds in which it occurs came to overlie the Dictyonema shales. On the margin of the old land the progress of the transgression is indicated by the overlap of the Arenig beds over the Tremadoc, the latter being absent in southern Scotland—the southern border of Caledonia—and in Brittany and Normandy—the northern border of Armorica. In like manner the Ceratopyge beds are wanting or represented only by shore sands in the Baltic provinces of Russia, and they are similarly overlapped by the later Ordovicic beds in Jämtland (Sweden). The Phyllograptus shales of the Atlantic came in contact with the Megalaspis limestones of the Siberian sea and the two likewise interfinger in the Baltic region. In the southern embayment the transgression included northeastern Spain and southeastern France before the end of Tremadoc time, but did not reach Bohemia until well along in Arenig time. When the northern Scottish region and a part of the northern border of Caledonia were submerged cannot be determined with precision, since the Beekmantown fauna, which alone existed there, can not be correlated in detail with the Atlantic or Siberian phases. Most probably, however, the early part of the Durness limestone (exclusive of the Cambric portion below the hiatus) belongs to the period of the Tremadoc and Ceratopyge sediments.

The second great event indicated by the sections is the retreat of the late Arenig Sea, until the Baltic region apparently became entirely dry and the Scandinavian lands were joined to Armorica. The withdrawal was westward to the Atlantic and eastward in the Siberian end of the channel. In southern Wales alone deposition appears to have continued, the Llanvirn series marking a transition from the Arenig to the Llandeilo, but also having distinctive characters, owing to the much contracted character of the embayment in which they were deposited. The Mediter-

ranean also seems to have been laid bare, though future studies in Sardinia and elsewhere may show a similar continuous series. Erosion no doubt occurred in many of the emerged areas, so that a part of the previously deposited Arenig was again worn away. As a result, also, basal conglomerates were formed and incorporated in the higher beds, when the sea again advanced.

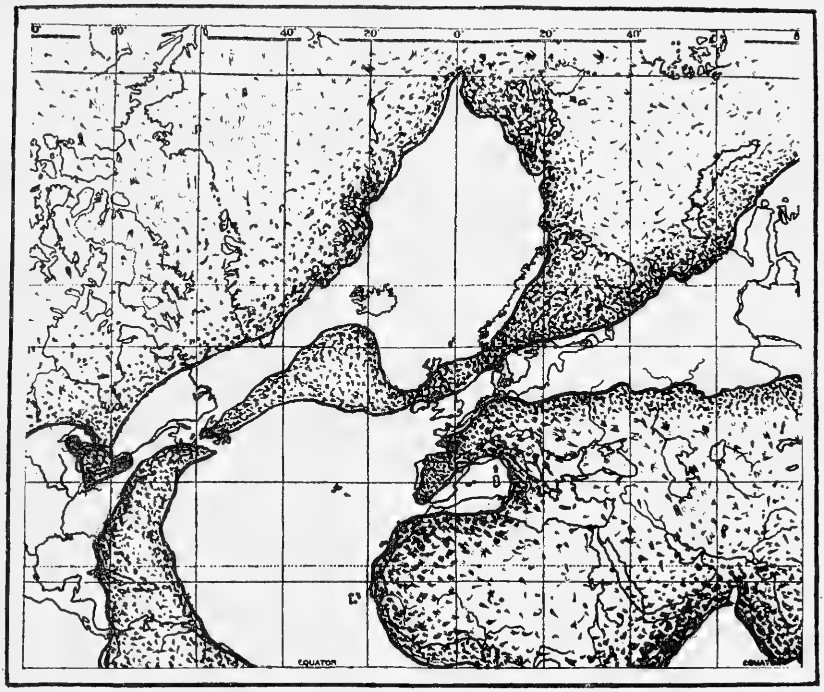

FIGURE 10.—*Paleogeographic Map of eastern America and western Europe and Africa in early Ordovicic Time*

Showing the three principal oceans—the Atlantic or Arenig-Llandeilo sea in the lower part, the Boreal or Beekmantown-Chazy sea in the upper center, and the Siberian sea on the right.

The readvance of the sea was apparently contemporaneous with the whole of Llandeilo and at least a part of Caradoc time. As shown by the different sections, Lower Llandeilo beds succeed the hiatus in some places and Upper Llandeilo in many more. Again, some of the regions were not covered until Caradoc time, as shown by the succession of these beds next above the hiatus. As in previous transgressions, the Siberian trilobite fauna and the Atlantic graptolite fauna came in contact in the Baltic region, where more or less interfingering and overlap of the two series is

recorded. The slow westward transgression of the Siberian Sea in the Baltic is shown by the progressive overlap of the lower by the higher members of the series.

The period of initial transgression corresponds to the Potsdam and early Beekmantown (Little Falls) transgression in North America. The first retreat, in late Arenig time, corresponds to the great Beekmantown retreat and the period during which the St. Peter sands were widely spread over central North America. The readvance during Chazy time corresponds to the readvance in the Llandeilo, and as in that case different members of the Chazy rest on the erosion plane or the reworked St. Peter, the successively higher members of the Chazy overlapping the earlier ones. Finally, the Black River beds overlapped the Chazy and the early Trenton beds in turn overlapped the Black River, as in various portions of the Canadian and the Rocky Mountain region.

It thus appears that these movements were simultaneous in Europe and North America, and that hence they belong to the changes of level due to diastrophism, expressed in the lowering and the raising of the sealevel all over the earth. Accordingly, breaks in the series as here described should occur between the corresponding formations in many other parts of the world. The paleogeographic conditions for western Europe are expressed in the map (figure 10) on the previous page.

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TRIASSIC IGNEOUS ROCKS IN THE VICINITY OF GETTYSBURG, PENNSYLVANIA[1]

BY GEORGE W. STOSE AND J. VOLNEY LEWIS

(Read before the Society December 29, 1915)

CONTENTS

[1] Manuscript received by the Secretary of the Society May 12, 1916.
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Distribution and Mode of Occurrence; by George W. Stose

INTRODUCTION

The area here described and shown on the map (figure 1) covers the Fairfield, Gettysburg, and Carlisle quadrangles and the immediately adjacent region. These three quadrangles were surveyed by the writer for publication in folios of the geologic atlas of the United States. The mapping of the adjacent region is taken from published State geologic maps of Maryland and Pennsylvania somewhat modified.

The Triassic igneous rocks of this area, with the possible exception of a thin sheet just south of Bendersville, are all intrusive diabase and include one large sheet, several cross-cutting bodies, and many small sheets and dikes. Their distribution is shown on the accompanying map, figure 1. The concealed and weathered condition of the exposures make it difficult to determine the mode of occurrence of some of the masses, but the relations shown in the sections (figure 2) are probably correct for the portions near the surface. The vent shown on the sections through which the molten magma is believed to have ascended is of course hypothetical, but is based on the facts described and the conclusions reached in this paper.

SEDIMENTARY ROCKS

The Triassic sedimentary rocks of this area almost invariably strike northeast and dip northwest from 10° to 35°, with an average of 15° to 20°. Along the western border, although local pronounced dips were observed, the bedding is on the whole nearly horizontal. The lower beds at the east are red micaceous sandstones and sandy shales interbedded with harder light-gray micaceous sandstones and arkose. At and near the base there are a few thin beds of quartz conglomerate, limestone conglomerate, and black fissile shale. This division is the representative of the Stockton formation of eastern Pennsylvania and New Jersey. The middle portion is chiefly soft red shale. The upper portion comprises both hard and soft red sandstones and shale and harder gray sandstone, culminating at

the west in coarse quartzose conglomerate and limestone conglomerate. These two divisions probably represent the Brunswick shale of eastern Pennsylvania, as the Lockatong type of sediment apparently does not reach this region, but ends south of Pottstown, Pennsylvania, as described by A. C. Hawkins.[2] The Triassic is abruptly terminated on its western edge by a normal fault.

Assuming that the beds are not repeated by faulting, as no evidence of strike faults was observed within the Triassic of this area, it is computed from the dip of the beds that there is represented here 23,000 feet of strata, but at no place in the area does this thickness occur. At the western edge of the basin, where, because of the continuous westward dip of the beds across the basin and the great drop fault, the greatest thickness of strata should be expected, the Triassic deposits are very thin, and the limestone floor on which they rest is exposed in the lowlands near York Springs and about Fairfield for nearly 3 miles horizontally under the Triassic. Although the floor of the basin is believed to descend much more rapidly east of these places, as shown in the sections (figure 2), nowhere in the basin will the thickness of the beds approximate the total thickness of the deposit, because the beds successively overlap westward on the limestone floor.

IGNEOUS ROCKS

The main igneous mass in the area is the great Gettysburg sill, which begins at Emmitsburg, Maryland, a short distance south of the Pennsylvania line, passes northeastward near Gettysburg, and ends a short distance east of Dillsburg. It has an average width of over 1 mile and expands to over 2 miles in places. By its relations to the sedimentary rocks it is shown to be a sheet intrusive in the westward dipping strata, its upper surface being clearly exposed in the Gettysburg battlefield reservation dipping 20° northwestward under the shale. Its general thickness is about 2,000 to 2,500 feet. That the sheet is somewhat cross-cutting, however, is indicated by the fact that it gradually rises in its position in the beds southwestward, as shown by the stratification lines on the map and by minor irregularities of its outline and width, which are believed to be due to cross-cutting. Some of the more regular offsets, as those east of Gettysburg, are probably caused by faulting. The marked expansion in width in the northeastern part of the Gettysburg quadrangle is apparently a local thickening of the sill, accompanied by cross-shearing of the sedimentary beds and greater uplift of the covering strata.

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[2] A. C. Hawkins: Lockatong formation of the Triassic of New Jersey and Pennsylvania. Annals N. Y. Acad Sci., vol. xxiii, 1914, pp. 145-176.

A large cross-cutting body near the south end of the Gettysburg sill, about 1 mile thick, cuts the strata at right angles and extends northwestward nearly to the western edge of the Triassic basin. From this cross-cutting body several sills are sent out. One forms the loop of in-

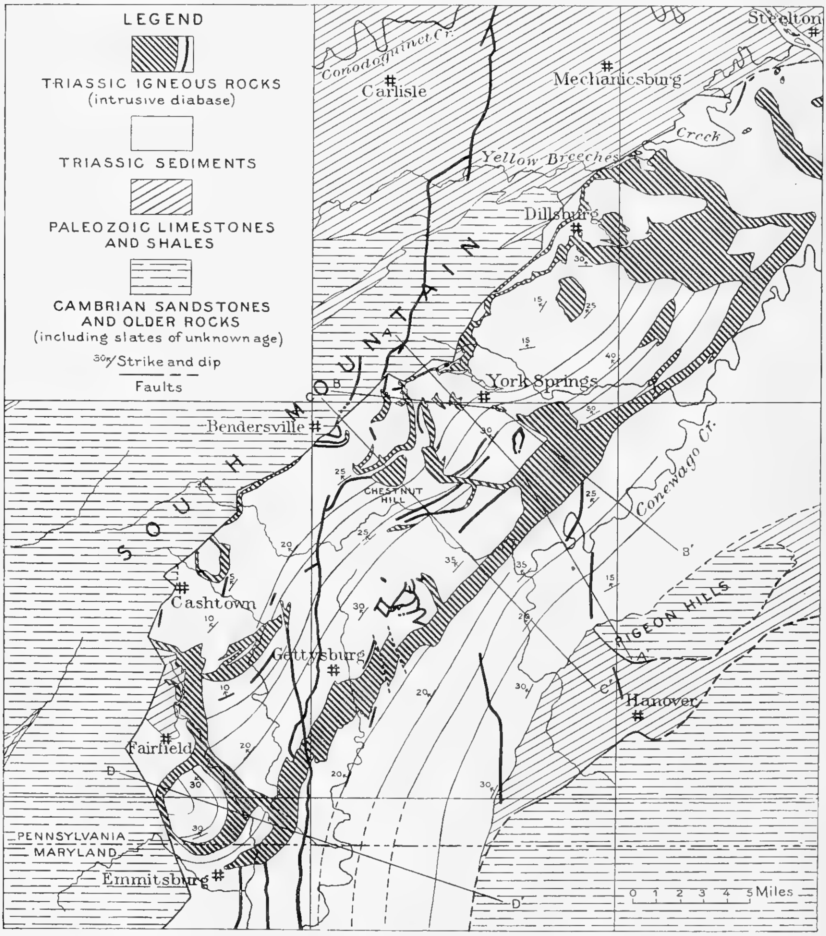

FIGURE 1.—*Geologic Map of the Vicinity of Gettysburg, Pennsylvania*

Includes the Fairfield, Gettysburg, and Carlisle quadrangles and portions of adjacent areas. The fine lines in the area of Triassic sediments represent distinct sedimentary layers that have been traced.

trusive diabase north of Emmitsburg—a sheet folded into a basin shape (see section D-D′). It is, however, cross-cutting in part, as shown by the truncation of the stratification lines on the map. On the northeast

it is still united with the cross-cutting mass. Two sills leave the cross-cutting mass north of Fairfield. One extends northeastward between the bedding planes and appears to divide into 3 sheets, inclosing sedimentary layers in part of its course. The other lies west of the cross-cutting body and follows the flat contact of the overlapping Triassic sediments on the Paleozoic limestone. This sheet is apparently of wide extent and, although it rises somewhat into the sedimentary beds of the Triassic in places, it is generally at or close to the overlap contact and will be hereafter referred to as the "overlap-contact sill." This relation is well shown in the isolated igneous mass resting on the limestone north of Fairfield. At the western edge of the basin this sill is cut off by the bounding normal fault and is concealed beyond to the north. The loop of diabase northeast of Cashtown is a folded sheet apparently at a slightly higher horizon, but the band exposed along the western edge of the Triassic farther northeast is probably the outcrop of the overlap-contact sill. The narrow loops of diabase at Bendersville are thin folded sheets apparently higher above the base, and one of them seems to be a surface flow. The overlap-contact sill is identified again in the valley northwest of York Springs, where it rests on the Paleozoic limestone floor.

A short cross-cutting body leaves the upper side of the Gettysburg sill 5 miles northeast of Gettysburg, and a longer one branches off 5 miles farther on. The latter sends off several small sheets between the sedimentary layers on both sides, and at its western end, where it swells to greater dimensions, a larger intrusive body leaves it and runs northward. This body is believed to be a sheet which is extensively exposed also in adjacent valleys to the west and east and is there overlain by thick beds of conglomerate. Since the conglomerate is known to overlap the Paleozoic limestone floor nearly horizontally from the western border of the Triassic to York Springs in a near-by valley, it is believed that the limestone floor lies only a short distance below the intrusive sheet just described, which is even nearer the western border, and that this sheet is the same as the overlap-contact sill which was traced northward from Fairfield. This is borne out by the fact that one of the areas of its outcrop connects at the north with the overlap-contact sill that lies on the Paleozoic limestone floor northwest of York Springs.

The diabase sill northwest of York Springs follows the limestone outcrop northward to where it disappears along the bounding fault. From there it passes northeastward toward Dillsburg, dividing into two bands, one terminating in the cross-cutting mass that extends east from Dillsburg, the other continuing past Dillsburg to another large cross-cutting body. These two cross-cutting bodies unite into one large mass which

forms the northern limit of the intrusive mass and connects with the north end of the Gettysburg sill.

The main intrusive body is thus seen to have the general form of a great trough that comes to the surface on the east as a great sill between the sedimentary strata and on the west as a sill along the flat overlap

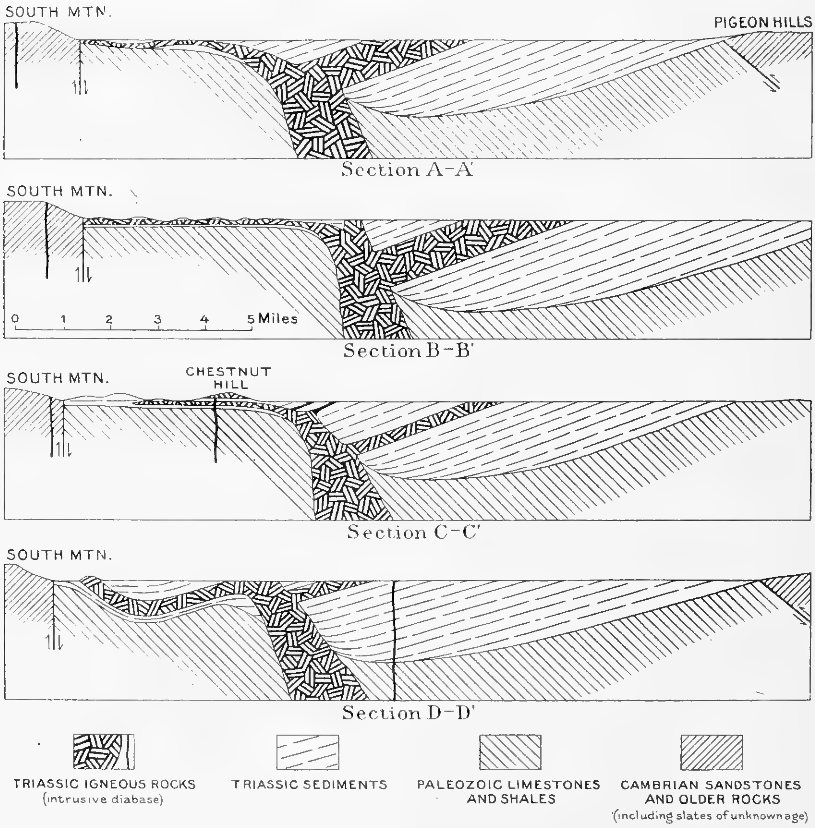

FIGURE 2.—*Sections across the Triassic Rocks of the Gettysburg Area*

The sections are along the lines marked on figure 1, and show the structural relations of the formations and the vent up which the igneous rock is supposed to have come into the basin. The vertical scale is somewhat exaggerated.

basal contact, and terminates at the ends in large cross-cutting bodies (see figure 2). That the trough is not complete throughout the area, however, is shown by the absence of the sill at the basal contact in the immediate vicinity of York Springs, where the Paleozoic limestone floor is overlain by Triassic sediments.

The Chestnut Hill igneous mass is a diabase sheet at a higher horizon,

apparently fed by the dike that joins it on the west. Its present shape suggests that it was of small lateral extent and relatively thick, so that it was of laccolithic habit; but since none of its cover is preserved this can not be positively determined.

There are many dikes and thin sills that cut the sedimentary rocks, some of which seem to connect with the Gettysburg sheet or the cross-cutting bodies; but others cut these rocks and are therefore of slightly later age, probably representing the last outburst of igneous activity from the same source. The dikes follow joint fractures, but no system seems to prevail, although the great number, especially the longer ones, trend nearly north and south. A network of such dikes and sheets occurs 3 miles northeast of Gettysburg. A chain of nearly continuous north-south dikes of great length crosses the area. The northern one of these dikes, which leaves the overlap-contact sill west of York Springs, has been traced across South Mountain into the Cumberland Valley and is known to continue across North Mountain—a distance of at least 25 miles. Another dike, whose connection with the former is not established, runs south from Chestnut Hill and joins the Gettysburg sill—about 15 miles distant. A third dike in the chain leaves the south end of the Gettysburg sill and has been traced for 40 miles across Maryland. These three dikes and their intrusive connections have a total length of about 90 miles.

CONCLUSIONS AND HISTORY OF TRIASSIC EVENTS

It is believed from a detailed study of the rocks and their relations that the progress of Triassic events was somewhat as follows: The sedimentary rocks were deposited in a sinking basin not directly connected with the sea; the sinking began in the southeast and progressed northwestward, so that the center of the basin of sedimentation shifted northwestward with the progressive sinking and the sediments overlapped on the Paleozoic limestone floor in that direction, the beds being tilted uniformly westward by the progressive sinking. The deepest part of the basin at the close of sedimentation was near the northwestern side, where the latest sinking had occurred, but not at the extreme northwest edge of the basin where the sediments are now seen overlapping nearly horizontally on the flat limestone floor and apparently have not been tilted by sinking. The sinking of the basin was accompanied by fracturing and probably faulting of its floor, particularly where the greatest sinking occurred. The progressive sinking of the basin and the later great depression of the block by drop faulting along its northwest edge were due to a lack of support from the rocks beneath, caused by internal movements of readjustment of equilibrium. This condition was accompanied by a re-

duction of pressure within the deeper-seated rocks sufficient to permit some of them, whose temperature was above their melting points, to liquefy. The molten material, still under pressure, but now free to move, followed the line of least resistance—upward in the zone of reduced pressure—and made its way along the joints, crevices, and fault-planes in the floor of the Triassic basin into the Triassic sediments. Here it wedged in between the northwestward-dipping beds and formed a great sill, while part of it ascended along the northwest base of the sediments between them and the flat floor of Paleozoic limestone, forming another great sill. The overlying strata between these sills was at the same time broken through by great cross-cutting bodies of the igneous mass and by smaller bodies that followed joint planes in the form of dikes. The elongated vent up which the molten magma came was probably at the western margin of the more deeply sunken portion of the basin, where the latest fracturing and faulting of the floor of the basin would have occurred. The further sinking of the Triassic basin resulted in a great irregular fracture along its northwestern side, along which the whole Triassic block settled several thousand feet, carrying the Paleozoic limestone floor far below the base of the Cambrian quartzites of South Mountain.

It seems probable that the molten rock of the large sheets and cross-cutting bodies must have reached the surface, unless the thickness of Triassic sediments was much greater than is supposed, and poured out as lava, as it did in the northeastern part of the Triassic basin in New Jersey; but such surface flows, if they did exist in this area, have been removed by the later erosion that carried away the higher sedimentary beds. A possible exception is found in the western edge of a thin sheet that reaches the boundary fault one-half mile south of Bendersville—the middle one of the three small concentric sheets. Here the igneous rock is basaltic, in part highly vesicular, and much decomposed; and there is a gradation from this to red shale in which are imbedded only scattered fragments from the disintegrating ledge.

Petrography; by J. Volney Lewis

SUMMARY

The igneous rocks are dominantly diabasic, but show a remarkable diversity of differentiation facies and a corresponding variety of physical characteristics. They range from coarse-grained granitic texture and pink to light or dark gray colors in the larger bodies to dense black rock in the contact facies and in thin sheets and dikes.

The chief constituents are a greenish black pyroxene and a whitish to gray plagioclase, largely andesine-labradorite. The pyroxene generally preponderates, but at many places feldspar is approximately equal in amount and locally it is in excess. The microscope shows plentiful magnetite, minute apatite crystals, and generally some quartz and orthoclase—these latter very commonly in micrographic intergrowth. Locally in the darker varieties there is much hypersthene or olivine or both, while in the lighter facies quartz and orthoclase abound. Here and there biotite is observed and, far less commonly, titanite.

Not uncommonly the pyroxene is altered in part to uralitic amphibole or to serpentine and chlorite with granular magnetite. The corresponding alteration of the feldspars yields fine scaly (apparently sericitic) aggregates and, less commonly, kaolin. In places epidote is abundant.

The texture is typically diabasic—the pyroxene filling angular interstices in a felted ground-mass of slender plagioclase feldspar crystals. By the coalescence of the pyroxene into larger areas, in which the feldspars are imbedded, the texture becomes ophitic. Dense varieties grade into typical basalt with glassy ground-mass—some with scattered phenocrysts of pyroxene and, in places, feldspar and olivine. In the more acid facies of the rock there is much quartz and orthoclase, either in separate grains or in micrographic intergrowth or both. These occupy angular spaces among the plagioclase crystals and there is much less pyroxene.

The order of crystallization is prevailingly diabasic—that is, the plagioclase was completed before the pyroxene—but there are two marked exceptions: (1) Pyroxene forms prismatic crystals in some of the coarser quartz-orthoclase facies of the rock, in which plagioclase is a subordinate constituent; (2) there are pyroxene phenocrysts in the dense black dikes, thin sheets, and contact facies, in which feldspar phenocrysts are few. Thus the earlier crystallization, probably antedating the intrusion, followed the usual order in plutonic rocks and would have produced a gabbro. In the normal diabase the order has been: (1) Apatite, (2) magnetite, (3) olivine, (4) plagioclase, (5) pyroxene, (6) micrographic quartz and orthoclase, (7) orthoclase, (8) quartz.

The varieties described are: (1) *Normal diabase,* the most common pyroxene-plagioclase rock; (2) *feldspathic diabase,* or *anorthosite,* chiefly plagioclase feldspar; (3) *quartz diabase,* with abundant quartz, much of it in micrographic intergrowth with orthoclase; (4) *micropegmatite,* consisting in the main of micrographic quartz and orthoclase; (5) *aplite,* essentially a dense granular quartz-orthoclase rock; (6) *hypersthene diabase,* with much hypersthene, replacing in part monoclinic pyroxene; (7) *olivine diabase,* with abundant olivine; (8) *basaltic diabase,* or *basalt,*

dense black facies, in places vesicular and having a glassy ground-mass; (9) *olivine basalt,* the dense black variety, with abundant olivine.

The areal distribution and delimitation of these varieties can not be determined without much more detailed work in the field and the aid of great numbers of thin sections—work that is out of the question, even if desirable, at the present time. Furthermore, the boundaries, in part at least, would have to be drawn arbitrarily, since gradational facies exist in some places, as shown by thin sections already in hand.

Strongly contrasted facies are apparently closely associated in places, as in the occurrence of highly feldspathic along with olivine-bearing basaltic types southeast of Bendersville. In the larger bodies the probability of some gravitational differentiation seems to be indicated, similar to that observed in the Palisades of the Hudson. This is particularly true of the Gettysburg sheet, where acid feldspathic and quartzose facies seem to dominate in the middle and upper (westerly) parts, although not to the exclusion of some more basic rock, while black, heavy hypersthenic and olivinic facies are typically developed near the bottom along the easterly contact. The outcrops here, however, are neither so continuous nor so fresh as in the Palisades, and the extent to which such differentiation has occurred would be difficult to determine.

GENERAL CHARACTER OF THE DIABASE

The larger intrusive masses, both in the sheets and the cross-cutting bodies, present a different appearance in the main from the dikes and thin sheets, although they are obviously parts of the same original magma. Indeed, some of the most strongly contrasted types are parts of one continuous mass, and all of them are doubtless united in a similar manner at no great depth. As a rule, the larger bodies of diabase are coarse grained, with colors ranging from light pink and gray to dark gray, and some of it is quarried and marketed as granite. The dikes and thin sheets, on the other hand, are fine-grained to dense rock and are nearly black.

In normal diabase, which is the prevalent type, the most important constituents are greenish black pyroxene and a white or grayish plagioclase. The pyroxene commonly preponderates, but in many places the two minerals are approximately equal and locally the feldspar is in excess. Crystals and irregular grains of magnetite and minute slender needles of apatite are rather plentiful and there is generally a little quartz and orthoclase. The darker varieties of the rock contain locally much hypersthene or olivine or both, while in the lighter facies quartz and orthoclase abound—as a rule, intergrown in greater part as micropegmatite. Here and there biotite is present in much smaller amount and, far less commonly, titanite.

The pyroxene is rather commonly altered in part to uralitic amphibole, serpentine, or chlorite, generally with more or less granular magnetite. A corresponding partial alteration of the feldspars has given rise to fine, scaly, apparently sericitic, aggregates and less commonly to kaolin. In places epidote is also an abundant secondary constituent.

TEXTURES

The size of the mineral grains in the rock has undoubtedly been determined in the main by the rate of cooling of the magma. Thus the coarser rock occurs largely in the thicker portions, which retained their heat and took much longer to crystallize than the thin sheets and dikes. In the very coarse quartz-bearing facies, however, the degree of liquidity has also been an important factor. These portions of the rock doubtless represent the last remnants of the magma which had become highly fluid, perhaps almost a watery solution, by the concentration of the volatile constituents from much of the adjacent magma that had crystallized earlier. The dikes and thin sheets are even denser, as a rule, than the contacts of the larger masses, and some of them are so homogeneous in appearance that their igneous character is not readily detected, even with a hand lens, although it may generally be inferred from the greater weight of the rock in comparison with the dense black variety of shale.

In the typical diabasic texture the angular spaces among the interlacing lath-shaped plagioclase crystals are occupied by pyroxene. With increasing proportions of the latter mineral it forms larger continuous areas in which the feldspars are imbedded, producing the ophitic texture. These textures are visible in hand specimens of the coarser varieties; but in the finer grained and dense varieties the aid of the microscope is required, and the thinner dikes and sheets show all gradations to typical basalt with glassy ground-mass. Scattering phenocrysts of pyroxene and, less commonly, of feldspar and olivine are developed in some of these denser facies. In the varieties containing much quartz and orthoclase, whether in separate grains or in micrographic intergrowth, these minerals occupy most of the angular spaces among the plagioclase feldspars and there is much less pyroxene. With increasing abundance of quartz, orthoclase, and the micrographic intergrowth of these minerals in approximately equidimensional grains, there is a falling off of plagioclase and the texture becomes granitoid.

ORDER OF CRYSTALLIZATION

From the diabasic texture of most of the rock, it is obvious that the crystallization of the plagioclase feldspar was quite generally completed

before that of the pyroxene. To this general rule there are, however, two exceptions: (1) In some of the coarser grained feldspathic and quartzose facies of the rock, in which orthoclase is the chief feldspar and plagioclase is much less abundant, the pyroxene has a well developed prismatic form and has evidently preceded the bulk of the feldspar in crystallization. (2) The common occurrence of pyroxene phenocrysts in the fine-grained contact facies of the larger intrusives and in the dense black dikes and thin sheets, with only here and there a large feldspar, indicates that the conditions of earlier crystallization, probably antedating intrusion, would have led to the completion of the pyroxene before the feldspar and the production of a rock of gabbroic texture.

Apatite and magnetite show by their crystalline form and their indifference to the other minerals that they were among the first products of crystallization. Here and there an inclusion of apatite in magnetite shows that the former mineral preceded the latter. Olivine, where it occurs, came before both the pyroxene and the feldspars, in both of which it forms inclusions. Orthoclase and quartz were the last constituents to crystallize—first in micrographic intergrowth, where this was formed, and then as separate grains of the two minerals, with quartz alone filling the last interstices. The prevailing order of crystallization in these rocks may be enumerated therefore as follows: (1) Apatite, (2) magnetite, (3) olivine, (4) plagioclase, (5) pyroxene, (6) micrographic quartz and orthoclase, (7) orthoclase, (8) quartz.

VARIETIES

General description.—Differentiation of the diabase magma has given rise to numerous well defined varieties in which the minerals occur in widely varying proportions. Thus (1) *normal diabase* is the prevalent pyroxene-feldspar aggregate already described; (2) *feldspathic diabase,* or *anorthosite,* consists chiefly of plagioclase feldspar; (3) *quartz diabase* contains abundant quartz, largely in micrographic intergrowth with orthoclase; (4) *micropegmatite* consists essentially of the graphic intergrowth of quartz and orthoclase; (5) *aplite* is a dense granular quartz-orthoclase rock; (6) *hypersthene diabase* carries much hypersthene, which replaces in part the common monoclinic pyroxene; (7) *olivine diabase* has abundant olivine; (8) *basaltic diabase,* or *basalt,* is the dense black facies, some of which is vesicular and has a glassy ground-mass; (9) *olivine basalt* is the dense black variety, with abundant olivine.

Normal diabase.—Except near the contacts, the rock of the larger bodies, both sheets and cross-cutting masses, is for the most part medium fine to coarse grained and ranges in color from light gray and pinkish to

dark grayish black. It is composed chiefly of greenish black pyroxene and white to gray plagioclase feldspar, with scattered grains of magnetite. In the coarser varieties the presence of orthoclase can generally be recognized in the hand specimen—locally in large amount—and visible quartz is commonly associated with it.

While there is some variation in the proportions of the pyroxene and feldspar, in many places they are approximately equal or one is not greatly in excess of the other. As a rule, the elongated feldspars are in contact with one another and the pyroxene in broader detached areas fills the spaces between, constituting the typical diabasic texture. Less commonly the pyroxene is in such excess that the feldspars are more or less isolated in it, producing an ophitic texture. Grains and crystals of magnetite are included in both of these constituents and minute needle-like crystals of apatite occur as inclusions in all three. In nearly all specimens of the normal granular diabase micrographic intergrowths of quartz and orthoclase, with here and there also separate grains of these minerals, occupy small scattered areas among the elongated plagioclase laths. Not uncommonly a little biotite accompanies the pyroxene and magnetite, but small grains of pyrite and chalcopyrite are rare.

Feldspathic diabase, or anorthosite.—With the decrease of pyroxene, plagioclase becomes the dominant constituent of the rock. Pyroxene constitutes only about one-third and one-fourth of the rock, respectively, in specimens from near the eastern border of the main sheet east of Gettysburg and from the cross-cutting body that extends westward from it at the extreme southern border of the Fairfield quadrangle, 6 miles southwest of Gettysburg. At the latter locality the pyroxene is reduced to small grains and stringers among the relatively large feldspars, and the rock from both places is light gray to nearly white in color. Both contain magnetite and minute needles of apatite, but a little micropegmatite and a few scattered grains of quartz are found only in the latter. A remarkable association of extreme types is shown in specimens from the thin sheet 1¼ miles southeast of Bendersville, where a rock having the megascopic characters of this feldspathic facies is closely accompanied by the dense black basaltic type. A similar basalt from the same sheet three-fourths of a mile farther east proves on examination with the microscope to be an olivine basalt.

Quartz diabase.—Micrographic quartz-orthoclase and plagioclase in approximately equal parts are the chief constituents of coarse-grained white, pink, and gray facies of the diabase in many localities. Pyroxene forms less than one-half and even less than one-fourth of the rock, with the usual small amount of magnetite and apatite. Quartz and orthoclase are

commonly present also in separate grains. Numerous large grains of quartz are distinctly visible in several places, and in some specimens crystal terminations are seen in miarolitic cavities. Scattered grains of yellowish brown titanite are readily recognized in the coarse-grained white variety from the Biggs quarry, 1 mile south of Gettysburg. In this rock, also, the pyroxene is in the form of lath-shaped prisms up to 20 millimeters in length and a little biotite is visible. Decrease in plagioclase results in the transition to micropegmatite, and in some localities aplite is also associated with this facies.

Micropegmatite.—Consisting chiefly of quartz and orthoclase in micrographic intergrowth, this variety of pink to pinkish gray rock is much like the quartz diabase described above and shows gradations into it. The texture ranges from medium fine to coarse grained. Quartz and orthoclase in large separate grains are common constituents, while plagioclase is very subordinate and in some the pyroxene is almost entirely lacking. This type is well represented at several localities.

Aplite.—Associated with quartz diabase and micropegmatite is an aplitic facies of the rock consisting of a fine-grained aggregate of quartz and orthoclase, with subordinate plagioclase, shreds of pyroxene, and scattered grains of magnetite and apatite. Numerous irregular grains of titanite occur in the pink aplite, which is abundant in the cross-cutting body 6 miles northeast of Gettysburg.

Hypersthene diabase.—Both orthorhombic and monoclinic pyroxenes are present in hypersthene diabase. Several specimens from the lower and middle portions of the Gettysburg sheet and one from the apophysis 6 miles to the northeast contain hypersthene in varying proportions, from about one-fifth to more than one-half the total pyroxenes, and in all cases these minerals exceed the feldspars in amount. A little biotite is found also in all of them, but the micrographic intergrowth of quartz and orthoclase is a constituent of only one specimen. The hypersthene shows the usual pleochroism in shades of red and green. A specimen of olivine diabase from near the bottom of the Gettysburg sheet also contains a little of this mineral.

Olivine diabase.—Fresh rounded grains of olivine of all sizes, from minute granules to about the average texture of the rock, constitute about 10 per cent of the bulk of the olivine diabase above referred to from the Gettysburg sheet. The rock is of medium fine texture and of dark brownish black color. Hypersthene is present and a small amount of biotite, but micropegmatite and quartz are absent. Otherwise the rock is similar in all respects to normal diabase.

Basaltic diabase, or basalt.—Basaltic diabase, fine grained to dense and nearly black, constitutes the dikes and thin sheets and the contact facies of the larger masses. Scattered phenocrysts of pyroxene and less commonly of feldspar and olivine are found in many places; otherwise the texture is entirely aphanitic. This facies of the rock, particularly where a glassy base persists, is essentially a basalt similar to that which constitutes the lava flows of the same magma in the Watchung Mountains of New Jersey. In the holocrystalline type the texture is prevailingly diabasic, with pyroxene generally in excess of feldspars. Abundant magnetite, uniformly disseminated through the rock in the form of minute granules, accounts in large measure for the black color. Locally, larger grains and crystals of magnetite occur, some in beautiful skeleton form. Minor accessories include a little biotite, minute needles of apatite, and scattered phenocrysts of olivine in places or serpentine pseudomorphs of this mineral.

Olivine basalt.—Basaltic diabase grades into typical basalt, as stated above, and this occurs both with and without scattered grains of olivine. In places this mineral is so abundant as to constitute typical olivine basalt. The thin sheet east of Chestnut Hill is also vesicular at the top. A dark-brown glassy base, thickly sprinkled with granules and skeleton crystals of magnetite, is abundant in a specimen from a thin sheet southeast of Bendersville. In places the magnetite is so abundant as to render the glass black and opaque.

PETROGRAPHIC DETAILS

Pyroxene.—The common monoclinic pyroxene is nearly black in the hand specimen, but is pale green to almost colorless in thin sections. Exceptionally it exhibits a slight pleochroism in shades of pale green and light greenish yellow. Having generally crystallized later than the feldspars, it has no crystal boundaries. The elongated prisms in some coarse pegmatitic varieties and the scattered phenocrysts in some of the basaltic facies are exceptions. Common types of twinning are those parallel to (1) the orthopinacoid (100), producing paired halves; and (2) the basal pinacoid (001), in repeated thin lamellæ, probably due to stresses in the rock. Magnetite and biotite, where it occurs, are common inclusions, and here and there minute apatite crystals, although the latter is more abundant in the feldspars and quartz.

Some degree of alteration to uralitic amphibole or serpentine, less commonly to chlorite, is almost universal. One of these secondary products usually predominates almost to the total exclusion of the others, although all of them are found together in some sections. The uralite in turn

alters to serpentine or chlorite. The pyroxene contains but little alumina, and that required for chlorite is undoubtedly derived in the main from accompanying feldspars. This is further shown by the fact that scales of chlorite have developed in the feldspars, as well as in minute veinlets that intersect all the minerals, proving the migration of its constituents. The secondary minerals after pyroxene are commonly darkened by granules, and in some places trellis-like skeleton crystals, of magnetite. Locally these are so abundant as to blacken the whole space occupied by the original pyroxene. Calcite is rare among the decomposition products, even in the most altered specimens.

Hypersthene.—With the exception of pleochroism and parallel extinction, hypersthene has the general appearance and characteristics of the monoclinic pyroxene. It alters to uralitic amphibole and serpentine, although, as a rule, it is fresher than the monoclinic pyroxene.

Plagioclase feldspar.—Generally the plagioclase forms the well known lath-shaped or rod-shaped crystals, but in some of the rock of coarser texture, with much quartz and orthoclase, it is much less elongated and the texture approaches the granitic. Terminal planes are commonly lacking and twinning lamellæ are universal, commonly according to the albite law, although pericline and carlsbad twinning are also observed. Zonal structure is rather common and, fringing the extreme acid borders, a graphic intergrowth of orthoclase and quartz generally fills some of the smaller interstices. Extinction angles correspond generally to an andesine-labradorite. Apatite, magnetite, and olivine occur as inclusions. The plagioclase most in evidence in the microscopic study seems to be largely andesine-labradorite, but chemical analyses of similar material from other localities shows the presence of a much wider range of feldspars.

Alteration gives rise chiefly to a confused fine scaly aggregate with high double refraction, apparently sericite (paragonite?), with a little kaolin in places. With migration of iron and magnesia from the pyroxene, chlorite is developed, as described above.

Orthoclase, microcline, quartz.—Quartz and orthoclase in micrographic intergrowth are very common, but separate grains large enough to be seen in the hand specimen are generally present in the lighter colored coarse-grained varieties of the rock. In these, areas of micropegmatite 3 or 4 millimeters in diameter are so abundant in places as to constitute three-fourths of the rock or more. Microcline is comparatively rare. Orthoclase is commonly much more altered than plagioclase—generally to a chalky kaolin-like substance, but in places to sericitic aggregates.

Magnetite.—Magnetite commonly forms 5 per cent of the rock or less. The grains and crystals are generally smaller than the associated pyroxenes and feldspars, and some of them form inclusions in both of these constituents. Lattice-like and dendritic skeletons are common. Some of these are beautiful aggregates of minute octahedrons. Secondary magnetite is commonly abundant among the alteration products of pyroxene. Masses that are molded irregularly about and among the plagioclase crystals are doubtless of this character—at least in part.

Biotite.—Small amounts of biotite are scattered through the finer grained contact facies and larger irregular flakes are clustered about the magnetite and pyroxene of the coarser grained rock. In places it is apparently secondary after pyroxene. It is altered in part to chlorite. The great bulk of the normal diabase contains little or no biotite.

Olivine.—Olivine occurs in the finer grained rock chiefly as scattered phenocrysts, which are generally altered, in part at least, to yellow or yellowish brown serpentine. Somewhat rounded and irregular grains are common, but some have crystal outlines.

Apatite.—Apatite in minute crystals occurs in all varieties of the diabase and forms inclusions in all the other constituents, but chiefly in the feldspars and quartz. It forms slender hexagonal prisms, with maximum dimensions of 0.07 by 2.0 millimeters, although most of them are much smaller and appear needle-like under the microscope.

Pyrite and chalcopyrite.—Small grains of pyrite and chalcopyrite are occasionally seen in hand specimens of the diabase, but they are rarely recognized in the thin sections.

Titanite.—Grains and crystals of titanite are abundant in the pink aplite facies of the apophysis 6 miles northeast of Gettysburg and in the coarse white quartz diabase south of Gettysburg. The latter rock contains elongated prisms of pyroxene and radial clusters of epidote in crystals up to 15 millimeters long.

Tachylite, basalt glass.—Dark-brown glass forms an abundant groundmass in the black olivine basalt southeast of Bendersville. It is thickly sprinkled with granules and crystals of magnetite and in places is black and opaque with them. The olivine basalt east of Chestnut Hill has a vesicular crust 8 millimeters thick, which is probably glass in part; but the dense rock immediately adjacent to this crust is entirely crystalline.

CHEMICAL COMPOSITION

Composition of various types of diabase.—Analyses of Triassic diabase from various parts of the Atlantic slope agree in general character, but show considerable variation corresponding to their diverse mineral

constitution, as illustrated by the examples in the following table. It is to be regretted that none of the rocks of this immediate district have been analyzed; but the following analyses from other areas are given here as a suggestion of the variations that probably occur in the rocks of the Gettysburg area. No analyses of the extreme quartz-orthoclase types—aplite and micropegmatite—are available from any part of the region. These would undoubtedly show much higher silica and alkalies and lower lime, iron, and magnesia than any of the examples quoted here.

Analyses of various Types of Triassic Diabase[3]

	1	2	3	4	5	6	7
SiO_2	60.05	56.78	51.68	46.87	55.31	50.88	49.02
Al_2O_3	11.88	14.33	15.87	13.36	13.64	13.17	10.14
Fe_2O_3	3.22	5.76	1.46	9.79	0.52	1.11	1.54
FeO	10.21	9.27	8.43	2.71	8.49	9.66	10.46
MgO	0.85	1.58	7.84	4.35	12.73	13.05	17.25
CaO	4.76	5.26	11.08	14.70	12.41	10.19	8.29
Na_2O	4.04	3.43	1.86	4.64	1.40	1.17	1.59
K_2O	2.10	1.75	0.34	2.01	0.32	0.31	0.40
H_2O+	0.66	0.10	0.15	....	....	0.14	0.59
H_2O-	0.21	0.33	0.16	....	....	....	0.16
TiO_2	1.74	1.44	0.72	1.98	tr.	....	0.99
P_2O_5	0.52	0.36	0.12	....	tr.	....	0.11
MnO	0.28	0.25	0.15	....	tr.	tr.	0.16
	100.52	100.64	99.86	100.41	100.82	99.67	100.70
Sp. gr.	2.872	....	....	....	....	....	3.152

1. Quartz diabase (dacose, II. 4. 2. 4). Pennsylvania Railroad tunnel through the Palisades, 400 feet from the west portal, Homestead, New Jersey.

2. Quartz diabase (tonalose, II. 4. 3. 4). About 420 feet from the upper surface of the sheet, Rocky Hill, New Jersey.

3. Diabase (auvergnose, III. 5. 4. 3). Rocky Ridge, Maryland.

4. Diabase (kilauose, III. 5. 2. 4). Birdsboro, near Norristown, Pennsylvania.

5. Hypersthene diabase (auvergnose, III. 5. 4. 3). The Twins, Culpeper County, Virginia.

6. Olivine-hypersthene diabase (auvergnose, III. 5. 4. 3). The Twins, Culpeper County, Virginia.

7. Olivine diabase (palisadose, IV. 1^2. 1^2. 2). The Palisades, Englewood Cliffs, New Jersey.

[3] Numbers 1 and 7, by R. B. Gage (Ann. Rept. Geol. Survey of New Jersey for 1907, p. 121); 2, by A. H. Phillips (Amer. Jour. Sci., vol. viii, 1899, p. 267); 3, by A. E. Schneider (Bull. U. S. Geol. Survey, No. 148, p. 90); 4, by H. Fleck (19th Ann. Rept. U. S. Geol. Survey, vol. vi, cont., p. 222); 5 and 6, by W. G. Brown (Bull. Geol. Soc. Am., vol. 2, 1898, p. 346).

Composition of the pyroxene.—Most analyses of pyroxene from the Triassic diabase show a moderately aluminous diopside. As compared with augite, there is a great excess of ferrous oxide and magnesia over lime, alumina, and ferric oxide. Analyses 1 to 4 in the following table may be regarded as approximately equivalent to a combination of diopside with common aluminous augite in proportions ranging from about 3 : 1 to 1 : 1, with small amounts of alkalies, indicating the presence of the acmite molecule. Number 5 approaches more nearly a typical augite.

Analyses of Pyroxene from Triassic Diabase [4]

	1	2	3	4	5
SiO_2	47.72	48.54	50.71	48.83	49.33
Al_2O_3	3.44	5.50	3.55	4.41	9.15
Fe_2O_3	5.93	2.77	....	....	0.27
FeO	18.34	21.25	15.30	9.00*	9.05
MgO	12.89	7.67	13.63	17.11	14.58
CaO	11.40	10.97	13.35	20.51	16.36
Na_2O	0.86	3.10	1.48 [5]	....	0.55
K_2O	0.37			....	0.19
MnO	....	....	0.81	....	....
Ign.	0.00	0.82	1.17	....	0.25
	100.95	100.62	100.00	99.86	99.73

1. From coarse-grained diabase from near the middle of the sheet, Rocky Hill, New Jersey. Pyroxene constitutes 41 per cent of the rock.
2. From quartz diabase 420 feet from the upper surface of the sheet, Rocky Hill, New Jersey. Pyroxene constitutes 45.6 per cent of the rock.
3. From diabase sheet, West Rock, New Haven, Connecticut.
4. From olivine diabase, near Chatham, Virginia.
5. From hypersthene diabase, Culpeper County, Virginia.

Composition of the feldspars.—The composition of the feldspars shows a wide range, corresponding in general to the differentiations as shown by the mineral constitution of the rock. Thus in the following table analyses 1a to 1d, from quartz diabase, range from nearly pure albite to andesine, associated with decreasing proportions of orthoclase; 2 and 3 show andesine-labradorite to labradorite from normal diabase, and 4 a more basic labradorite from hypersthene diabase. From the high percentages of silica, it is evident that free quartz was present in some of the specimens. Thus there is an excess of 20.6 per cent in 1a, 26 per cent in 1b, 11 per cent in 3b, and smaller amounts in the others.

[4] Numbers 1 and 2, by A. H. Phillips (Amer. Jour. Sci., vol. viii, 1899, p. 267); 3, by G. W. Hawes (Amer. Jour. Sci., vol. ix, 1875, p. 185); 4, by T. L. Watson (Amer. Geol., vol. xxii, 1898, p. 98); 5, by W. G. Brown (Bull. Geol. Soc. Am., vol. 2, 1891, p. 344)

* Determined as Fe_2O_3 10.01.

[5] By difference.

Analyses of Feldspars from Triassic Diabase [6]

	1				2		3		4
	a	b	c	d	a	b	a	b	
Sp. gr.	>2.69	<2.69	<2.60	=2.577	>2.69	<2.69	>2.69	<2.69	
SiO_2	66.84	71.68	66.28	66.79	53.84	62.26	52.84	60.54	51.40
Al_2O_3	17.98	15.02	16.79	19.36	29.30	21.87	28.62	24.11	30.98
Fe_2O_3	2.60	2.48	1.60	0.91	0.81	0.54	1.52	1.14	0.22
MgO	0.48	0.12	0.13	0.13	0.28	0.15	0.46	0.27	0.45
CaO	5.02	3.86	0.71	0.80	10.08	6.53	11.81	9.15	13.40
Na_2O	5.46	5.52	9.76	7.34	5.31	7.98	2.38	4.11	2.85
K_2O	1.72	1.37	5.31	4.95	1.16	1.20	0.86	1.06	0.39
Ign.	0.72	0.00	0.49	....	0.44	0.32	1.06	0.59	....
	100.82	100.05	101.07	100.28	101.22	100.85	99.55	100.97	99.69
Per cent of rock	23.1	13.4	6.5		32.2	14.3	....	....	....
Plagioclase	ab_2an_1	ab_3an_2	$ab_{26}an_1$	$ab_{17}an_1$	ab_1an_1	ab_2an_1	ab_2an_5	ab_7an_9	ab_3an_8

1. From quartz diabase, 420 feet from the upper surface of the sheet, Rocky Hill, New Jersey.
2. From diabase, near middle of the sheet, Rocky Hill, New Jersey.
3. From diabase, Pennsylvania Railroad cut, Jersey City, New Jersey.
4. From hypersthene diabase, The Twins, Culpeper County, Virginia.

[6] Numbers 1 and 2, by A. H. Phillips (Amer. Jour. Sci., vol. viii, 1899, p. 267); 3, by A. B. Howe (Proc. U. S. Nat. Mus., vol. iv, 1881, p. 129); 4, by W. G. Brown (Bull. Geol. Soc. Am., vol. 2, 1891, p. 343).

MINERAL COMPOSITION

The proportions of the various mineral constituents in certain facies of the Triassic diabase have been determined from thin sections by the Rosiwal method, with the results that are given in the following table. No measurements have been made on aplite and micropegmatite, some specimens of which are composed almost exclusively of quartz and orthoclase in approximately equal amounts.

Mineral Composition of certain Facies of Triassic Diabase

	(1)	(2)	(3)	(4)	(5)	(6)
Quartz	19	7	..	..	..	..
Feldspar	44	42	37	20	38	18
Pyroxene	27	34	59	73	46	58
Biotite	3	..	..	1	1	1
Olivine	..	..	1	4	13	20
Magnetite	7	17	3	2	2	3

1. Quartz diabase, Pennsylvania Railroad tunnel through the Palisades, 400 feet from the west portal, Homestead, New Jersey.
2. Quartz diabase, 420 feet east of the station platform, Marion Station, Jersey City, New Jersey.
3. Diabase, the Palisades, Englewood Cliffs, New Jersey.
4. Diabase, the Palisades, near West Shore Railroad ferry, Weehawken, New Jersey.
5. Olivine diabase associated with number 4.
6. Olivine diabase, the Palisades, horseshoe curve of the trolley line, Edgewater, New Jersey.

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GLACIAL LAKES AND OTHER GLACIAL FEATURES OF THE CENTRAL ADIRONDACKS*

BY HAROLD L. ALLING

(Presented by title before the Society December 29, 1915)

CONTENTS

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The writer is indebted to Professors James F. Kemp, Herman L. Fairchild, and especially to Prof. George H. Chadwick, for advice and counsel, both in the field and in the laboratory.

Introduction

In his presidential address before the Geological Society of America, delivered December 28, 1912, Professor Fairchild introduced his subject, "The Pleistocene Geology of New York State," by remarking that "in variety and excellence of Pleistocene phenomena New York State probably excels any other equal area of the earth's surface."[1]

This being so, it is regrettable that the large area occupied by the Adirondacks should still be inadequately shown on our maps of Pleistocene geology. In the central area of this region, especially the Mount Marcy, the Lake Placid, the Ausable, and the Elizabethtown quadrangles, have not yet received the attention they deserve; for while the mapping of the rocks has, apparently, been done with considerable thoroughness, the glacial geology has been generally overlooked, although in the accessible valleys it is so clearly discernible that "he who runs may read."

[1] H. L. Fairchild: Bull. Geol. Soc. Am., vol. 24, p. 134.

It has fallen to the writer to attack the problems of the glacial geology of the central Adirondacks and to attempt to present, as best he can, something of the wonderful history there to be deciphered. In such pioneer work many mistakes and false conclusions are apt to appear, for it is impossible to avoid errors in an undertaking of such magnitude and complexity as is there found.

The great variety of glacial deposits and the interesting series of local glacial lakes, with their attendant deltas, beaches, and outlets, are sure to attract the glacial geologist when the region is better known. Especially striking are some Pleistocene cataracts in a number of the outlet channels, that remind us of Cataract Lake Park, in the neighborhood of Syracuse.

Multiple Glaciation

Although positive evidences of multiple glaciation in the Adirondacks are not forthcoming, pre-Wisconsin glaciation in Pennsylvania, New Jersey, and New England has been established so as to lead us to the conclusion that this area also has been subjected to continental ice-bodies more than once. In some of the brook valleys the depth of the drift is enormous and often a difference in the character of different levels can be detected. If evidence is to be found of pre-Wisconsin ice-action in the Adirondacks, it is in such deposits.

The Laurentian Ice-body

EXTENT AND THICKNESS

It is generally conceded that at the maximum extent of the ice the Adirondacks were completely buried, and it has been estimated that this ice must have been 8,500 to 12,000 feet in altitude[2] over the central Adirondack region. To this enormous load on the land surface is attributed the well observed phenomenon of deformation, to which we will return later.

MOVEMENT

It is generally accepted that the ice-sheet moved across the area in a southwesterly direction, although very few striæ have been observed within the area itself. In the table given below the glacial scratches are presented as noted by a number of geologists and are also indicated on the accompanying map. In the Champlain Valley the direction was southward, but farther to the west the striæ swing to the west of south with

[2] H. L. Fairchild: Bull. Geol. Soc. Am., vol. 24, p. 136. After Shackleton.

an average direction of about south 45° west, influenced, no doubt, by radial flow and to a greater extent by the topographical features that culminate in the major faults which make the region interesting to the physiographer. The striæ in the valleys are, undoubtedly, due to the last stages of the ice-movement, for subsequent weathering has entirely destroyed the glacial scratches on the mountains which would have indicated the general direction of the ice-flow.

EROSIONAL WORK

Although there is a difference of opinion as to the destructive power of the continental glacier, the mountains must have been scraped clean of the decomposed rock surface resulting from atmospheric action. The bare slopes of Pitchoff Mountain, on the southern edge of the Lake Placid sheet, furnish an excellent example of such action.

The many amphitheaters and little rocky pockets on the mountain sides, so noticeable in the Adirondacks, are due, in all probability, to the erosive action of ice. These cirques have been by some attributed to the work of local glaciers.[3] Excellent examples are visible on the slopes of the highest mountains, such as Giant, the Gothics, and Basin, as well as on the sides of Whiteface and Sentinel.[4]

The origin of rocky pockets occupied by ponds on the southwestern slopes of some of the mountains is not clearly understood, but the plucking action of the ice may be regarded as a contributing cause. Lost Pond, in the southwest corner of the Ausable sheet; Little Pond, on Ellis Mountain, and the Giant's Washbowl are typical. The almost universal position of these little lakes on the southwestern slopes of the mountains gives weight to such a theory.

In pushing through the major faults, such as that of the Cascade Lakes, the Wilmington Notch, and the fault of the Middle Kilns, the ice carried with it the talus material that had accumulated during interglacial periods, freshened up the valley walls, and left U-shaped valleys, blocking both ends with crescent-shaped moraines as it retreated.

The occurrence of glacial boulders is quite common, some of which appear to have been transported great distances, while others can be traced to parent ledges in the neighborhood. In Keene Valley the boulders are often quite large, sometimes as large as a small house. They are much more plentiful on the west side of the valley than on the other, again indicating the southwestward ice-flow. Rounded boulders of Potsdam

[3] I. H. Ogilvie: Glacial phenomena in the Adirondacks. Jour. Geol., vol. 10, 1902, pp. 397-412.

[4] J. F. Kemp: N. Y. State Mus. Bull., vol. 21, p. 62.

Glacial Striæ

Meridian	Striæ	Quadrangle	Township	Location	Observer
73° 45′ (?)	S. 12° W.	Lake Placid	Jay	Southeast of Upper Jay	J. F. Kemp.
73° 51′	S. 62° W.	Lake Placid	Wilmington	West of river, 3 miles northwest of Wilmington.	J. F. Kemp.
73° 47′	S. 10° E.	Lake Placid	Keene	1¼ miles north of Keene	H. L. Alling.
73° 47′	Due south	Lake Placid	Keene	1½ miles north of Keene	H. L. Alling.
73° 48′	Due south	Mount Marcy	Keene	¾ mile south by west of Keene	J. F. Kemp.
73° 45.5′	Major, S. 30° W. Minor, S. 45° W.	Ausable	Jay	Lower Jay, east bank	H. L. Alling.
73° 40′	S. 71° W.	Ausable	Black Brook	½ mile west of Ausable Forks	H. L. Alling.
73° 37.5′	S. 62° W.	Ausable	Ausable	2¼ miles west of Clintonville	H. L. Alling.
73°	S. 30° W.	Ausable	Ausable	3 miles northeast of Clintonville	H. P. Cushing.
73°	S. 40° W.	Ausable or Dannemora	Ausable	2 miles north of Clintonville, near Peru township line.	H. P. Cushing.
73° 36.5′	S. 52° W.	Elizabethtown	Elizabethtown	New Russia	J. F. Kemp.
73° 35.1′	S. 32° W.	Elizabethtown	Elizabethtown	¼ mile northeast of Elizabethtown	H. L. Alling.
73° 34.3′	S. 25° W.	Elizabethtown	Lewis	1¾ miles northeast of Elizabethtown	H. L. Alling.
73° 30.5′	S. 70° W. S. 65° W.	Elizabethtown	Moriah	Southeast corner of sheet	J. F. Kemp.

Direction of major Faults

Meridian	Direction	Fault	Quadrangle
73° 52′	S. 46° W.	Cascade lakes	Mount Marcy.
73° 50′	S. 45° W.	Ausable lakes	Mount Marcy.
73° 54′	S. 46½° W.	Wilmington Notch	Lake Placid.
73° 51′	S. 53½° W.	Middle Kilns	Lake Placid.

It is interesting to compare the direction of the striæ with the direction of the major faults.

quartzite have been noted all over the four quadrangles. At Cascadeville, between the two Cascade lakes, a boulder of Beekmantown limestone was found.

Large irregular slabs of Potsdam sandstone and quartzite are encountered in some of the brook valleys, where the drift is abnormally thick. In the valley in which the old Weston iron mine is located, not far from Keene Center, slabs are very common at an altitude of about 1,600 feet and do not appear to be glaciated, the natural inference being that a ledge of the Potsdam existed there before the ice-invasion broke it up. "The former extension of the Potsdam formation over all or the greater portion of the Elizabethtown and Port Henry sheets is clearly demonstrated by a small outlier observed by Professor Kemp."[5] . . .

Dr. D. W. Johnson, of Columbia, suggested to the writer that the sawtooth shape of the Niagara Mountain block fault in the southeast corner of the Mount Marcy quadrangle may have been preserved by the deposit in it of a ledge of Potsdam sandstone that was subsequently eroded and destroyed by the ice, while most of the other faults, such as that containing the Cascade Lakes, have been completely leveled.

Such phenomena lead directly to the conclusion that the Adirondacks were submerged in the Cambrian sea to a much greater extent than was formerly considered to be the case.

CONSTRUCTIONAL WORK

Moraines.—There is but little true morainal material[6] to be found in the Adirondacks, nor have true drumlins been noted. Most of the drift has been stratified by water. The movement of the ice during the maximum advance was too vigorous for deposition, and the material that was deposited as the ice retreated was modified by the action of standing water.[7]

The recessional moraines appear to be largely confined to the fault passes, being formed by the ice-tongues as they withdrew from the narrow passes. At the southwestern ends in the broad valleys the rate of retreat was slow and moraines were formed; but in the narrow defiles the ice retreated faster, giving but little opportunity for the deposition of material. Again, at the northeastern ends the ice-tongue paused long enough to deposit another moraine. Other recessional moraines are to be found in the more open valleys. Remnants of a crescent-shaped one are to be noted in the southwestern corner of the Ausable sheet, where it has been

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[5] Rudolf Ruedemann: N. Y. State Mus. Bull., No. 138, p. 62.
[6] H. P. Cushing: N. Y. State Mus. Bull., No. 115, p. 496.
[7] I. H. Ogilvie: Jour. Geol., vol. 10, 1902, pp. 397-412.

cut through by the Turpee Brook.[8] Far up Styles Brook there are a series of them, greatly modified by present stream work. These are given only as examples, as many more have been seen and others will undoubtedly be discovered as future work is undertaken.

Possible local moraines.—Lateral moraines, sometimes of rather perplexing character, are encountered in the brook valleys. In the Slide Brook Valley, in the center of the Mount Marcy sheet, and in some other of the brook valleys, occur apparently morainal ridges on either wall of the valley that are very like lateral moraines of local glaciers. It is possible, however, that these are remnants of bisected crescent-shaped recessional moraines, either of local glaciers (and therefore convex *down*stream) or of the main ice-body (convex *up*stream), the present streams having destroyed their original form. Two miles north of Keene coarse material, which some observers have considered as moraine, overlies stratified sand. These instances are mentioned as having a possible bearing on the problem of local glaciation in the Adirondacks.[9] The studies of J. L. Rich in the Catskill Mountains suggest that local glaciers prevailed there as well.[10]

Eskers.—Eskers are very uncommon. A long, narrow ridge of gravel and coarse sand was found in the Johns Brook Valley that was believed to be one. A very perplexing ridge with the appearance of an "eskerette" is responsible for the existence of Clear Pond, near the center of the Ausable quadrangle. Others will, undoubtedly, be found when more thoroughly sought.

Kames.—Kames are likewise rather rare. In the vicinity of the southwestern end of the Middle Kiln fault pass a number of irregular hills are strongly suggestive of this class of moraine.

Outwash plains.—Outwash plains can generally be distinguished from deltas and glacial lake bottoms by ice-block kettle-holes. Frequently, in the field, such distinctions are difficult, if not impossible, to make unless accompanied by other positive evidence. Such is the problem that is met in the South Meadows country, in the northern portion of the Mount Marcy sheet. Several kettle-holes dimple the somewhat level surface of this great sand plain. A possible correlating outlet channel, described later on, would incline the writer to regard it as a glacial lake bottom. Our present knowledge is not conclusive, and a difference of opinion exists among several geologists, whose experience has led them to take opposing views on the matter.

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[8] J. F. Kemp: N. Y. State Mus. Bull., No. 138, p. 19.
[9] I. H. Ogilvie: Jour. Geol., vol. 10, 1902, p. 405.
[10] J. L. Rich: Am. Jour. Sci., vol. xxxix, Feb., 1915, p. 154.

Morainal damming.—The preglacial drainage has been profoundly modified by morainal deposits of one kind or another in numerous localities. Old river courses have been filled and valleys dammed. Frequently the streams have been able to cut through such barriers and flow through drift-filled valleys little altered in character. On the other hand, some river courses have been altered and now flow in postglacial channels. Two excellent examples of stream diversion may be mentioned. One is in the East Branch of the Ausable River a little south of Keene. In the comparatively broad valley we note an unnamed hill, around the two sides of which the two highways leading into Keene Valley circle. To the east of this hill the present stream rushes between steep walls of Grenville schist and syenite, experiencing rapids and falls. It is clearly a postglacial channel and is one of the beauty spots in the central Adirondacks. On the other side of this hill the preglacial channel is plainly perceptible, now blocked by sand and gravel of a lateral delta.

A similar state of affairs occurs at the Split Rock Falls of the Bouquet River, south of New Russia, in the Elizabethtown quadrangle. The falls are of recent origin. The old channel lies deeply buried to the west, where Coughlin Brook is attempting to cut its way through the drift.

Many of the lakes and ponds of the Adirondacks are caused by the damming of preglacial valleys. Lake Placid, for example, has resulted from the damming of two fault-line valleys that have been joined by channels following cross fault-lines producing a ladder-shaped body of water. In a depression in the surface of this dam Mirror Lake now lies.

A striking morainal ridge in the Chapel Pond fault pass has retained the surface of the pond on one side of the pass at a higher altitude than Beede Brook. On this ridge the highway runs, affording the geologist an excellent opportunity to observe this phenomenon.

Glacial Lakes

GENERAL OBSERVATIONS ON THE ORIGIN OF THE LAKES

Several important conditions have produced two distinct series of local glacial lakes in the central Adirondacks. The first condition was a valley sloping toward and blocked by the ice-front. The second was the isolation of such a valley by mountain ranges. Both the Keene and Elizabethtown valleys fulfilled these conditions to such an extent that considerable time will be devoted to the description of the different lakes that existed in them.

There are two series of these lakes—one in the East Branch of the Ausable, called the Keene Valley group, and the other in the valley of the Bouquet River, known as the Elizabethtown group.

KEENE VALLEY GROUP

Upper series—Western section.—As the ice-sheet began to wane, the highest peaks of the Adirondacks were the first to become uncovered, and played the rôle of islands in a sea of ice.[11] Slowly these islands became larger, surrounded by a growing accumulation of water impounded by the ice. The waters found escape over the ice to the south and eventually passed to Susquehanna drainage. This process of melting was continued until entire mountain ranges were exposed.

South Meadows Lake (altitude, 2,000 to 2,040 feet).—The falling waters, still hemmed in by the ice, came finally to a pause sufficiently long enough to leave a group of terraces and sand plains at the present altitude of 2,000 to 2,040 feet, chiefly in the South Meadows country. This great sandy deposit, already referred to, is open to two interpretations: first, that it is an outwash plain spread out by the waters from the retreating ice; and, second, that it is a glacial lake bottom. The writer is inclined to favor the latter hypothesis, and so has proposed the term "The South Meadows Lake."

Although the terraces of this lake are chiefly found on the Mount Marcy sheet, the adjacent corners of the Santanoni and Saranac quadrangles exhibit remnants.

The fill in the South Meadows is enormous. It must have taken a long time for entering streams to wash such a large amount of material into the standing waters of the lake. Undoubtedly the original surface till furnished some of the material. The terraces blend with the boulder drift on the mountain slopes and attain an altitude of something over 2,100 feet at the valley walls. A number of kettle-holes dimple its surface, several of them now occupied by ponds, Round Lake being an example.

The position of the northern ice-front at this stage is not definitely known, but no terraces have been found north of a line drawn east and west across the Lake Placid quadrangle through the southern end of the lake. On the Saranac and the Santanoni sheets the ice is for the present assumed to have lain on a line connecting the summit of Ampersand Mountain and the shore of Lake Placid at the point where Whiteface Inn is now located. This position is suggested on the basis of a probable outlet for the lake to the west as follows. It begins at the swamp just south of Alford Mountain, in the Santanoni quadrangle, on the Essex-Franklin County boundary line, it passes westward through the narrow pass (altitude, 1,960 feet) directly south of Van Dorrien Mountain to

[11] H. L. Fairchild: N. Y. State Mus. Bull., No. 160, pl. 11.

the shore of Ampersand Lake, thence south of this lake to Blueberry Pond. Continuing westward into the Long Lake quadrangle, on the boundary between the two maps, it turns to the southwest and passes three-quarters of a mile south of Palmer Brook. When within a mile of the Raquette River the course turns directly south over Brueyer Pond. This river course is offered as a suggestion, as actual field-work has not been undertaken in the rugged and inaccessible Santanoni quadrangle.

The fault valley containing the Cascade Lakes was probably not a channel of the South Meadows Lake, although the matter is still open to further investigation. At both ends of the pass recessional moraines remain that evidently have not been cut by any large river. The altitude of the moraine at the western end of the valley is between 2,100 and 2,200 feet. Thus our present knowledge of the probable history of the South Meadows Lake would indicate that the Cascade fault was blocked by moraines and perhaps by an ice-tongue, preventing escape to the east. The outlet hence was to the west, as suggested above.

Eastern section—Keene Lake (altitude, 2,000 to 2,040 feet).—To the east of the Cascade fault pass in Keene Valley terraces of a glacial lake are found at an altitude of 2,000 to 2,040 feet, being the same altitude as that of the South Meadows, although apparently they had no connection with it. Terraces are found in the valley high up on the valley walls, especially in the brook valleys, where the present streams have bisected them. The Keene Lake was quite extensive, for Keene Valley was evidently filled by standing water that flowed in a gentle stream through the Ausable Lake fault pass, which acted as a connecting link between the Keene Valley section and the area surrounding and occupied by the famous Ausable lakes, the Boreas ponds, Elk Lake, and Clear Pond. Although the Boreas ponds, Elk Lake, and Clear Pond lie south of the present divide, in the Hudson drainage basin, the waters of the Keene Lake were, apparently, held from directly draining to the south by a southern ice-wall that lay in an east and west line across the upper portion of the Schroon Lake quadrangle.[12]

The glacial history of the double fault in which the Lower Ausable Lake now lies is difficult to decipher. It is because of the absence of any other possible outlet for the Keene Lake that this fault pass is believed to have performed that function, because the Chapel Pond and the Spruce Hill fault passes (the latter south of East Hill, on the junction of the Mount Marcy and Elizabethtown sheets) were blocked by ice-tongues that had pushed their way into them from the east, thus preventing the escape of water in that direction.

[12] H. L. Fairchild: N. Y. State Mus. Bull., No. 160, pl. 12.

Theoretically, it is conceivable that as the ice to the south lying across the Schroon Lake sheet gradually melted, the waters south of the divide were separated from the portion of the Keene Lake lying in the Ausable Valley, and so the Boreas-Elk-Clear Pond section became a distinct glacial lake, which in turn may have subdivided into the "Boreas Lake" and "Glacial Elk Lake," while the drainage of the remaining Keene Lake flowed into this Boreas Lake through the pass east of Moose Mountain.

The outlet of both these lakes was thus probably south or southwesterly around the projecting ice-lobe in the Boreas-Hudson River depression, although the eventual outlet channels have not yet been determined.

The terraces of the Keene Lake are rather poorly defined, but are sufficiently preserved to make possible the calculation of the Pleistocene deformation. Remains of terraces in the Ausable Lake region are on the 2,000-foot contour, while a small terrace to the east of the Lower Cascade Lake has an altitude of 2,040 feet. As these terraces are separated by a distance of 13 miles, the amount of warping since the Keene Lake stage is approximately 3 feet to the mile.

The Keene Lake is regarded as the younger of these two lakes, lying at the 2,000 to 2,040-foot level. The extensive fill in the South Meadows country is not duplicated in the Keene Valley, and the length of time required to fill the former basin was evidently far greater than that required to form the comparatively small terraces in the Keene Valley.

Eastern and western sections—Newman Lake (altitude, 1,740 to 1,875 feet).—The water level that apparently succeeded both of the lakes above described has considerable range, namely, from 1,740 to 1,875 feet. Here also the question arises whether or not this may not be an outwash plain. Our present knowledge is insufficient to enable us to settle the matter. The writer is again inclined to the view that this level has been formed in a glacial lake whose surface was being continuously or intermittently lowered by progressive melting of some body of ice that controlled the outlet. These high-level waters, in all probability, did not have rocky outlet channels, but flowed over ice; hence their indefinite character.

Extensive sandy plains of the Newman Lake are situated about Lake Placid. In the neighborhood of John Brown's grave terraces exist at two rather well defined levels, the lower one at 1,740 to 1,780 feet and the higher one at 1,800 to 1,820 feet. Remains of terraces are found in Keene Valley, chiefly on East Hill (the slopes of Hurricane Mountain), and in the Johns Brook Valley. Here the separation of the terraces seems impossible.

Around the railroad town of Newman, from which the name of the

lake was taken, and along the West Branch of the Ausable River (especially where the Lake Placid-Keene highway crosses) the terraces are splendidly developed and very impressive.

The Wilmington Notch is regarded as having been the connecting link between the Lake Placid and the Keene Valley districts. This hypothesis is supported by the presence of accordant terraces both east and west of the Notch. How else could the waters of the two areas have been confluent?

The most probable outlet of the lake was to the west. The flow, it would seem, was through the Newman pass, through which the Delaware and Hudson Railroad now runs, the ice having retreated northward since the South Meadows stage sufficiently to allow flow north of Ampersand Mountain. The possibility that the fault pass containing Chapel Pond, on the eastern edge of the Mount Marcy quadrangle, or the Spruce Hill pass to the north of it, acted as outlets to the east during the last stages of Newman Lake is rather doubtful, but not impossible. If either one of these passes did open up, it resulted in the reversal of the direction of the drainage and brought about a second phase of the lake.

Saranac glacial waters (altitude, 1,450 to 1,600 feet).—In 1897 F. B. Taylor[13] published a short paper describing "Lake Adirondack." Mr. Taylor observed terraces in the Saranac region at altitudes ranging from 1,400 to 1,600 feet. He believed that the lake existed by virtue of an ice-dam to the north. He says in part:

"It is not certain, but seems likely, that at the greatest extent this lake included the valleys of both the east and west forks of the Ausable River. This would give it quite an irregular shape with three expanded parts. For this I propose the name 'Lake Adirondack.'

"Nearly all the modern lakes in the central area of the mountains lie in basins only slightly depressed below this plain, which is between 1,400 and 1,600 feet in altitude."

Terraces are exhibited around Clifford Falls, up Styles Brook, where a wave-cut cliff was found, and in Keene Valley, especially between Baxter and Spread Eagle Mountains. In the Johns Brook Valley a terrace at 1,450 feet forms the site of a summer hotel.

The figures the writer has obtained for this series of glacial sand plains, for no single lake level could have produced such a wide range, are 1,450 to 1,600 feet, which agree fairly well with Mr. Taylor's figures. Professor Fairchild suggested that the drainage was westward and finally south, following a course close to the encircling ice-front on the west of the Adirondacks and draining into glacial lakes in the Black River Valley,

[13] F. B. Taylor: Lake Adirondack: Am. Geol., vol. 19, 1897, p. 394.

and thence through the pass at Boonville.[14] Channels may exist to the west of the Adirondacks that it will be interesting to correlate with these water levels when investigation is attempted.

This wide range of levels, as indicated above, leads us to the conclusion that they were not formed by any one lake, but by a series of falling glacial waters; so that the name "Lake Adirondack" is too restrictive. The term "Adirondack Waters" would be more accurate; but as all the waters of the different stages here described are Adirondack glacial waters, it seems desirable to use a more local name, and it is proposed that the term "Saranac Glacial Waters" be substituted for "Lake Adirondack." At least two-thirds of the Saranac quadrangle exhibit sand plains of these waters, the levels of which are so very indefinite that they appear to have been produced in water controlled by ice outlets. Although the drainage may have been westward, as suggested by Professor Fairchild, it is not impossible that the pass, a mile west of Black Mountain—altitude, 1,440 feet—was an outlet for this series of water levels to the east, or at least for their lower stages. This possible channel is described in more detail later on.

Saint Hubert Lake (altitude, 1,300 to 1,340 feet).—There is a small, but finely developed, terrace at the head of Keene Valley, at the point where the Chapel Pond road makes a steep ascent. The altitude is about 1,300 feet. The level surface is now used as a base-ball diamond. It was regarded, when first investigated, as the remnant of a morainal lake that was drained by the destruction of the barrier; but more extended field-work soon disclosed some rather ill-defined terraces at the same or slightly higher levels in various portions of the area covered. Among these are a number of terraces and sand plains on the hill traversed by the Keene-Cascade Lakes Road. While the remains of this 1,300-foot level are not as important as those of some of the other glacial lakes, they can not be ignored in a survey of the region.

Lower series—Confined entirely to the eastern section.—In descending from the higher lake levels to the lower ones, the character of the terraces changes from indefinite levels of considerable range to neat, clear-cut deltas, wave-cut cliffs, and kame-terraces confined within concise limits. No question can be raised as to their origin. They represent remains of true glacial lakes. The writer believes that when they are better known and appreciated they will be regarded as remarkable and highly instructive.

Wilmington Lake (altitude, 1,100 feet).—The history of the Wilming-

[14] William J. Miller: N. Y. State Mus. Bull., No. 135, p. 53.
H. L. Fairchild: N. Y. State Mus. Bull., No. 160, p. 39, stage 1.

ton Lake is, perhaps, at the present time the best understood of all these local glacial lakes. It was confined in a general way to the East Branch of the Ausable River and to the territory around the town of Wilmington and stretches northward almost to Ausable Forks.

The altitude is 1,100 feet at the foot of Johns Brook, in Keene Valley, where a typical delta was developed. A mile and a half southeastward of Keene, on the State road at Norton Cemetery, there is an excellent display of a bisected delta. In the same vicinity a view can be obtained embracing at one time successive terraces. They appear very distinctly, showing Keene Lake, Newman Lake, Saranac water level, possibly the Saint Hubert Lake, Wilmington Lake, and finally the Upper Jay Lake at 1,000 feet. Unfortunately a photograph does not bring them out as prominently as direct vision.

As one investigates the terraces of the Wilmington Lake farther north, in the Lake Placid and Ausable quadrangles, the altitude rises at a rate of 2.94 feet per mile, and illustrates post-lacustrine deformation in a clear and instructive manner. A number of beaches of the Wilmington Lake are beautifully shown on a hill one mile directly north of Keene Center. Here the altitude is 1,117 feet. Farther north we find the outlet channel spillway at 1,140 feet. This level, compared with the 1,100-foot delta above mentioned, gives, on calculation, a deformation of 2.94 feet per mile.

Cataract outlet channels.—When the outlet of the Wilmington Lake is considered, we find a display of glacial phenomena which makes it one of the most interesting regions of the Adirondacks; for in the center of the Ausable quadrangle, in a rather inaccessible country, a series of rock channels culminating in a number of Pleistocene cataracts are very beautifully shown.

During the Wilmington stage an ice-lobe lay in the East Branch of the Ausable with its southern wall a little south of North Jay. Another blocked the narrow valley now occupied by Trout Pond. Thus northward escape was prevented. The waters of the lake found their outlet to the east through the gulf, a narrow and deep major fault, south of Ellis and Black Mountains. The flow was through two unnamed little ponds, occupying slight depressions in the rocky bed. One-eighth of a mile to the east of them we encounter the first Pleistocene cataract of this remarkable channel. Unfortunately the topography as drawn on the map is defective and fails to show this feature. The crest of the now extinct falls forms a beautiful horseshoe, some 80 feet across, with a drop of 50 feet. The cliff is not as precipitous as is the Jamesville Cataract, in

FIGURE 1.—DISSECTED REMNANT OF WILMINGTON LAKE DELTA-TERRACE

At the foot of Johns Brook, half a mile south of Keene Valley. Looking west. Present altitude, 1,100 feet. Photograph by J. F. Kemp, 1915

FIGURE 2.—BEACHES 1¾ MILES NORTHEAST OF LOWER JAY, 790 AND 795 FEET IN ALTITUDE

Looking north. Higher beaches occur farther up on the hillside, obscured by the trees, at 994 and 1,030 feet. Photograph by H. L. Alling, 1915

GLACIAL DELTA-TERRACE AND BEACHES OF THE CENTRAL ADIRONDACKS

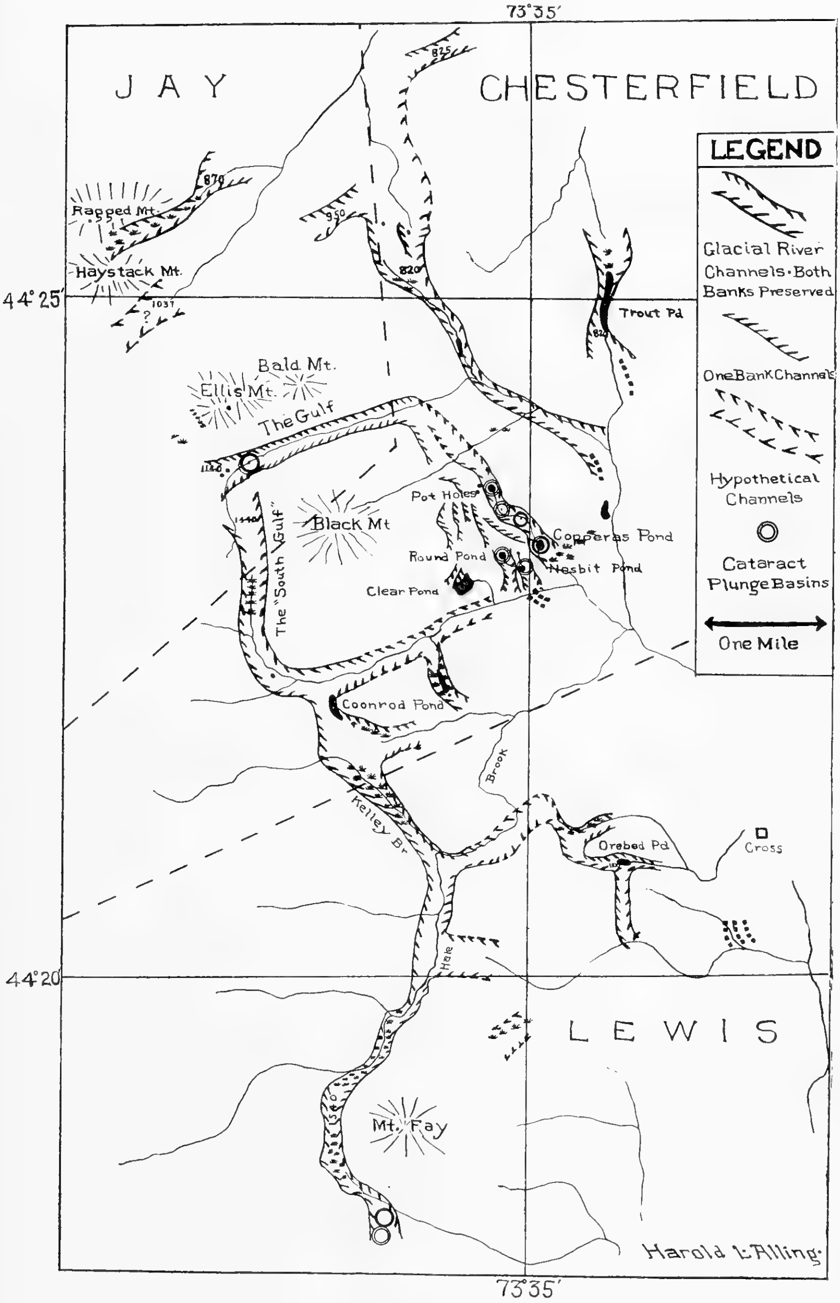

FIGURE 1.—*Glacial Channels in the Ausable Quadrangle*

Cataract Lake Park, southeast of Syracuse.[15] Here the rock is Grenville schist and metamorphosed graphitic limestone, more or less tilted on edge. This is eroded in quite a different manner from the Onondaga limestone that caps the falls of the 169-foot Jamesville Cataract. Thus it is not a sheer drop, but more of a steep cascade. At the base of the now extinct falls the original rock plunge basin is filled with swampy ground, and this, together with the trees and bushes that have grown up on the cliff, hides the cataract so that it cannot be appreciated unless tramped over.

For the lack of time the entire length of the gulf has not been investigated, and there is the possibility of more such interesting relics of glacial times being found. At the eastern end of the gulf, on the boundary between the townships of Jay and Chesterfield, the river course turns to the southeast, making for a series of little ponds. Here again the topography is in error. The second lake in the Chesterfield group, round in shape, is printed with the 940, 920, and 900-foot contours *below* it. They should be *above* it. This unnamed lake, lying in a perfect rock plunge basin, marks the base of another Pleistocene cataract with a drop of 45 feet. Careful scrutiny of the map will reveal two little pin-points of blue separated today by the 1,000-foot contour. They are now almost completely filled with vegetable debris, but were Pleistocene pot-holes in a glacial outlet channel. These are, however, not in the main channel of the Wilmington Lake outlet, but are in a higher level channel that had only one rocky bank, the other being the ice itself. A series of one-bank channels can be seen by climbing the steep slopes of Black Mountain. The rocky sides are strongly water-worn and leave little doubt as to their origin. What lake drainage is represented by these high channels is at present undetermined.

There are two other fine cataracts between the above-described lake and Copperas Pond. These are not represented on the topographic map, nor do they show so great a drop, but are equally as impressive in spite of subsequent avalanches. We reach the climax in Copperas Pond itself, a beautiful round sheet of water lying in an Alpine type of plunge basin at the foot of a precipitous wall of rock 80 feet high. The pond appears to be fairly deep, but has not been sounded. The shores of the lake are composed entirely of rock—Grenville quartzose schist. The present little trickle of an outlet flows over a majestic spillway worn smooth by icy torrents.

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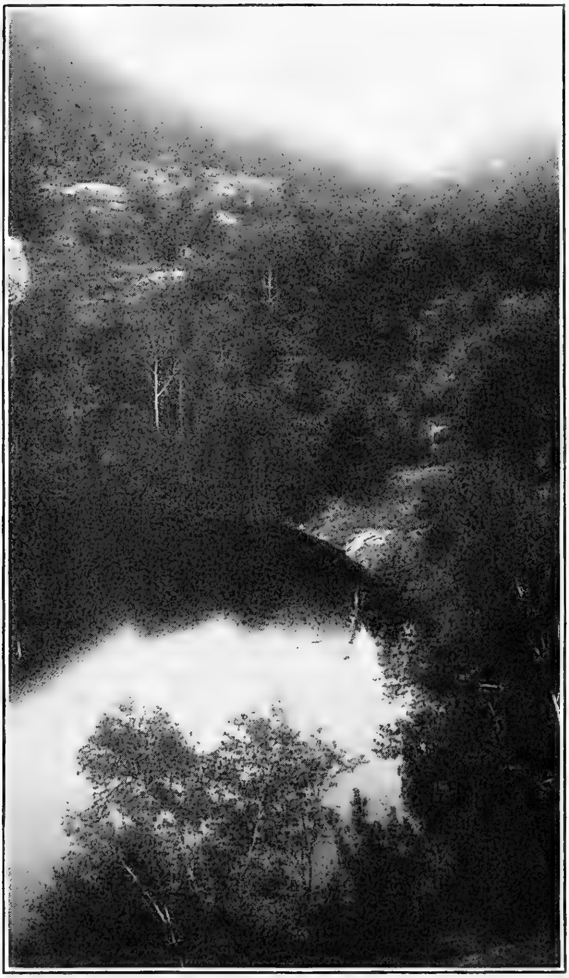
[15] E. C. Quereau: Topography and history of the Jamesville Lake. Bull. Geol. Soc. Am., vol. 9, pp. 173-182.

H. L. Fairchild: N. Y. State Mus. Bull., No. 127, p. 32.



COPPERAS POND, NEW YORK

Five and one-half miles south of Clintonville. Looking down from the southwest bank. Plunge basin in Wilmington Lake outlet channel. The extinct falls in the woods in the upper half of the photograph. Photograph by H. L. Alling, 1915.

Soon after leaving the Copperas Falls the water ran along the edge of the ice-lobe. Long boulder trains and boulder deltas extending from Copperas Pond to Cross give evidence of heavy stream-work.

In the same area a long glacial channel runs south from the intake of the gulf channel. It passes through the fault pass of the "South Gulf," as it is locally known (to the east of Black Mountain), through Coonrod Pond, through Kelly Brook, through Hale Brook, and through the swamp that encircles the western slopes of Mount Fay. Two small cataracts occur where the 1,400-foot contour makes curious bends near the road three miles northwest of Lewis. Various branch channels lead off from this long channel to the east and represent successive channels opened up by the retreating ice-lobe lying in the valley of the North Branch of the Bouquet River. This long channel was probably formed by the waters of Saranac time, the successive lake levels being produced by the uncovering of the side channels as indicated.

The most interesting side channel so far investigated contains Orebed Pond and the swamp a mile northwest of it. The contour map would indicate that there were at least two cataracts here, but field-work failed to reveal them; evidently the topography is incorrectly drawn.

The neighborhood of Copperas Pond contains several other cataracts. Both Nesbit and Round ponds are plunge basin lakes. Clear Pond is probably a morainal lake, with perplexing eskers and a morainal ridge damming the waters. The reader's attention is drawn to the present brook that flows through the Gulf. It will be noticed that the divide in the fault is at one end instead of in the center, as is the case with the majority of the major fault passes in the Adirondacks. Apparently the flow has caused the high point of the pass to retreat to the west as stream-cutting progressed.

The pass to the east of Black Mountain and the valley in which Trout Pond is now situated give evidence of the action of additional glacial streams. A very interesting combination of geological phenomena is displayed in the fault valley to the east of Pokamoonshine Mountain. Here is a typical block fault with the apparent downthrow to the east. The mountain cliff is composed of Grenville schist and "rusty" gneiss, while the valley rock is a granite-gneiss with a characteristic crushed zone between. On the very precipitous mountain face a series of trap dikes is beautifully shown. They have been faulted and bent since their intrusion. One dike, estimated to be about 15 feet wide, has been broken up into several pieces and offset from the original alignment. Along the fault-line a glacial river forced its way, removing to a large extent the crushed rock. What a wide range of geologic time is represented by

these features—the Grenville, the granite intrusive, the trap dikes, the faulting, and, lastly, the Pleistocene river channel!

Upper Jay Lake (altitude, 1,000 feet).—Returning to the description of the glacial lakes that existed in the valley of the East Branch, we find that the lake succeeding Wilmington left terraces at the present height of 1,000 feet. This has been called "Upper Jay Lake," and, like its predecessor, is very clearly defined. A wave-built spit at the foot of the Spruce Hill road near Norton Cemetery is exactly 1,000 feet in altitude, while a beach with a height of 1,030 feet, situated 1¾ miles southwest of North Jay, furnishes a basis for calculating the amount of warp, the figure being 2.79 feet per mile. The outlet of the lake is not definitely known, but a pass half a mile directly south of Haystack Mountain, in the Ausable quadrangle (not the mountain of the same name in the Marcy Range), has an altitude that gives us the proper figure when the deformation is computed. When visited, however, this pass did not show evidences of stream-work. The area is entirely fine sand, while farther to the northeast remains of crescent-shaped moraines stretch part way across the valley. A possible channel 1½ miles north of Bald Mountain is suggested as an alternative outlet.

The lakes following the Upper Jay Lake are very numerous and close together. Those described below, with their attached names, probably represent only part of the series, for the territory is rough and progress in the field is slow. Nevertheless they illustrate the fascinating Pleistocene history of this unusual country. They descend from 980 to 500 feet in altitude through the following steps: 980, 960, 935, 870, 840, 760, 680, and 500 feet. They will be treated briefly.

Haselton Lake (altitude, 960 feet).—A lake with the altitude of 960 feet around the town of Keene has left terraces, wave-cut cliffs, and beaches. The amount of warp based on beaches 1¾ miles southwest of North Jay and faint terrace cuttings on a hill near Keene is calculated at 2.63 feet per mile. Relatively small sand plains of this period are well shown about the town of Haselton Village in the Lake Placid sheet. The controlling outlet is unknown, but the writer offers the suggestion that it may have been a one-bank channel on the north side of Haystack Mountain (Ausable sheet) carrying the waters east to the ice-tongue.

Lower Jay Lake (altitude, 935 feet).—This lake is very definite and splendidly exhibited about Keene by several beaches situated at the lake level and by wave-cut terraces at 934, 935, 933½ feet, as determined by spirit-leveling. Farther north it becomes faint and no terraces or beaches have been found on which deformation can be based. There is, however, a fine sandy plain of this lake on the western edge of the Lake Placid

sheet a mile east of Upper Jay Village, which continues on to the Ausable sheet, where we find Otis Brook flowing on the eastern edge. Here the altitude is about 940 feet.

Otis Lake (altitude, 900 feet).—Between the 935 and the 870-foot levels there have been noticed a number of random beaches and terraces in the valley of the East Branch, all situated at 900 feet, with no apparent deformation. A beach near Keene, ill-defined terraces in the neighborhood of Upper and Lower Jay, also give evidence of what I have called Otis Lake.

Rocky Branch Lake (altitude, 860 to 880 feet).—Rocky Branch Lake is announced on the basis of three terraces around the villages of Upper and Lower Jay. The altitude ranges from 860 to 880 feet. Both the outlet and the deformation are unknown; nevertheless the terraces are definite in character and rank on a par with others.

Clifford Lake (altitude, 840 feet).—A little south of the junction of Clifford Brook and the Ausable River there is a benchlike terrace formed, apparently, by wave-cutting in a kame moraine of striking appearance and easily seen from across the river on the State road. The height is 840 feet. Farther north, five-eighths of a mile northeast of Lower Jay, a beach at 860 feet and the probable outlet half a mile south of Ragged Mountain give an approximate deformation value of 2.60 feet per mile. The river, after flowing through this pass, in all probability turned southward through the long, narrow pass to the east of Bald Mountain.

Styles Lake (altitude, 820 to 825 feet).—A series of terraces near the junction of Styles Brook and the Ausable and to the north of the same were formed by the Styles Lake. Some of them fail to line up perfectly, while others roughly fit the hypothetical plane. The controlling outlet channel may have been either one of two passes—the long channel east of Bald Mountain or the channel 2¾ miles directly south of Ferrona. The ice, it would seem, had retreated to allow the northern slopes of Ragged Mountain to act as a one-bank channel.

Wainright Lake (altitude, 760 feet).—Between the villages of Upper and Lower Jay terraces of a glacial lake with an altitude of 760 feet are observed at some distance from any appropriate geographical name. Wainright Mountain is the nearest feature; hence the name. A terrace and a beach, 760 and 770 feet respectively, in the vicinity of Upper Jay are too near together to give any accurate figure for the deformation.

Clintonville water level (altitude, 680 feet).—About Ausable Forks and Clintonville the most impressive Pleistocene features are the almost diagrammatic terraces at 680 feet. Great sandy plains stretch on both sides of the river. The most striking exhibit is the level down through

which the Ausable Branch of the Delaware and Hudson Railroad has made a deep cut. Here the level is like a table, and beautifully shown by the contouring on the map. This plain very probably represents the summit marine level of Professor Fairchild. The figure he has secured for this locality is 650 feet, which is 30 feet lower than the writer's. This discrepancy in elevation may be due to a grading up of the plain from a lower base level farther down the valley.

Keeseville water level (altitude, 500 feet).—On the junction corners of the Ausable, Willsboro, Plattsburg, and Dannemora quadrangles an extensive delta plain exists with an altitude of 500 feet. Beaches of this delta have been noted and mapped by Woodworth.[16] It seems fairly certain that this Keeseville level is marine in origin.

ELIZABETHTOWN GROUP

General observations.—Although the Elizabethtown group of glacial lakes is, perhaps, just as interesting as those in Keene Valley, it has not received the attention that it deserves. Several of the lakes have been observed and described by others, notably Dr. Heinrich Ries and Dr. William J. Miller, but the higher levels, the writer believes, are new to geological science.

Rhododendron Lake (altitude, 1,630 to 1,650 feet).—The highest glacial lake terraces so far discovered are situated in the Elizabethtown sheet in the Chapel Pond pass (Keene Township), in the neighborhood of Rhododendron Pond. Several destructive forest fires have swept through this fault valley in the past few years, rendering the region forbidding, but at the same time revealing the splendidly developed terraces lying at the altitudes of 1,630 to 1,650 feet. They are, as a rule, exceedingly bouldery and rough. They give the impression that they are morainal ridges modified by standing waters.

Bouquet Lake (altitude, 1,530 to 1,550 feet).—In the same region 100 feet lower we find another group of terraces of similar character. The extent of the lake is somewhat problematical, but it is supposed to have been considerable, in view of some indistinct terraces observed 2 miles northwest of Lewis (in the Ausable sheet) at 1,670 to 1,690 feet, which, if they belonged to this same lake, would indicate a deformation of something like 3 feet per mile.

Branch Lake (altitude, 1,300 to 1,340 feet).—Four miles west of Elizabethtown, in the Valley of the Branch, which is a continuation of the Spruce Hill Pass, there is exhibited a sandy plain of definite character at 1,300 to 1,340 feet in height.

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[16] Woodworth: N. Y. State Mus. Bull., No. 84, p. 170, and pl. 21.

It gives one the impression that it was a delta formed in standing water by inflowing streams. Two stream valleys to the north, Falls and Jackson brooks, are drift-laden and promise to reveal terraces of some higher lake levels when investigated.

North Hudson Lake (altitude, 1,150 feet).—In the valley of the Schroon River and New Pond Brook a badly eroded terrace plain is situated at 1,150 feet. In the vicinity of Euba Mills and Underwood the terraces are rather prominent. Areas about Lincoln Pond and 2 miles east of Elizabethtown appear to be plains of the same level.

Lake Pottersville (altitude, 900 to 980 feet; Holiday Lake, altitude, 980 feet).—"Along the Schroon River, just west of Holiday Pond, there is an extensive gravel terrace with pebbles up to 2 inches, and with its top at the 980-foot contour. There must have been ponding of water at this locality. . . . The character is such as to argue delta conditions, rather than a lake bottom. Still farther south a terrace is again pronounced between 940 and 960 feet, where the highway crosses and leaves the Mount Marcy sheet."[17]

In the Paradox quadrangle the same terrace is described by Doctor Ogilvie:

"The surface of this terrace is slightly uneven and suggests an origin of a kame terrace, which ice still stood in the valley. The front of this terrace has been extensively eroded in part by the Schroon River, which has built a lower terrace of floodplain origin, and in doing so has worn back the face of the older one; in part by recent gullying. . . . The material of this terrace is sand."[18]

Dr. William J. Miller has mapped a glacial lake—Lake Pottersville—extending over the North Creek, Schroon Lake, and Paradox Lake quadrangles.[19] He says in part:

"The best example of the sand flat delta deposit formed in the lake lies in the vicinity of Pottersville (North Creek sheet). The highest water-laid sands and gravels occur from one-third to two-thirds of a mile northwest of the village and at an altitude of nearly 900 feet."

Taking these figures together with the observations of the writer, the different terraces noted strongly suggest that they were formed by the same lake. The 900-foot delta at Pottersville and the 960 south of Holiday Pond agree, assuming a deformation of 3 feet per mile. Thus the writer has taken the liberty of using Doctor Miller's name for the lake.

In the Ausable quadrangle, 2 miles northwest of Lewis, a series of beautiful beaches is exhibited at the following heights: 920, 935, 952, 975,

[17] J. F. Kemp: N. Y. State Mus. Bull., No. 138, p. 20.
[18] I. H. Ogilvie: N. Y. State Mus. Bull., No. 96, p. 477.
[19] William J. Miller: N. Y. State Mus. Bull., No. 170, p. 70, fig. 10.

1,025, 1,060. The latter is a very strong beach. Assuming 3 feet of deformation per mile, calculation brings the 1,060-foot beach in line with the others. This, according to our present knowledge, would rank the lake as one of the longest of the glacial lakes in the Adirondacks.

Split Rock Lake (altitude, 770 feet).—In the vicinity of Split Rock Falls, on the Bouquet River, terraces and wave-cut moraines give evidence of a glacial lake at 770 feet. A mile or so to the north, near the junction of Beaver Meadow Brook, similar phenomena are splendidly developed. Little else has been observed as to the general character of this lake (see plate 22, figure 2).

Elizabethtown Lake (altitude, 660 feet).—Dr. Heinrich Ries was the first to describe the almost diagrammatic terraces and lake bottoms at Elizabethtown.[20] He believed that the lake that left these remains existed by virtue of a morainal dam at the head of the Bouquet Valley. He says in part:

> "Three and a half miles south of Elizabethtown is New Russia, and one and a half miles south of this town the valley broadens and continues so until north of Elizabethtown, where it narrows suddenly, the river flowing northward between Ravens Peak and Woods Hill. It is at this point that the dam of drift probably was which caused the lake, but on account of the steep sides of the valley little or none remains. The outlet of the lake must have been through this valley.
>
> "The present bottom of the valley between Elizabethtown and New Russia is from one-half to a mile across, so that the lake must have been at least this wide, while its depth in places was 100 feet or even more, as the level of the valley is 540 feet, while the shoreline is 660."

The writer has found some excellent beaches a quarter of a mile north of Lewis at 660 and 661 feet, and a storm beach at 675. Whether these beaches prove that the Elizabethtown Lake extended farther north than Doctor Ries thought is a question. At the same time the crescent-shaped moraine south of Lewis, already referred to, might have been a dam; not the one, however, mentioned by Doctor Ries, for the writer can not regard the Ravens Peak-Woods Hill moraine as an important factor. Nevertheless the beaches line up well. Moreover, the stretch of open sandy plains north of Mount Discovery is at the proper height to be considered part of the Elizabethtown Lake bed. If the "Lewis" moraine was the dam that caused the lake previously described, there existed a true glacial lake north of it at the same height, which is rather improbable. Hence the writer is inclined to consider that the Elizabethtown Lake was not a

[20] Heinrich Ries: Pleistocene lake bottom at Elizabethtown, New York. Acad. Sci., vol. 13, 1893, p. 109.

morainal lake, but a glacial lake extending from a point 2½ miles south of New Russia to Cross, 5 miles north of Lewis. This would make it quite extensive.

Black River water level (altitude, 510 feet).—On both sides of the present floodplain of the Black River, which lies to the east of Elizabethtown, terraces occur at 510 feet in altitude. They are definite enough to have been made by glacial or marine waters, although there is the possibility that they are remnants of river floodplains. The Black River is today a typical overburdened stream. It has produced extensive floodplains below the terraces, which can be easily observed from the Elizabethtown-Westport highway.

Summary of the Glacial Lake Succession

KEENE VALLEY GROUP

The ice-sheet first melted around the mountain peaks and gradually retreated down the slopes, taking the form of irregular rings of ice that held glacial waters. Continued melting exposed the upper ends of the South Meadows and Keene valleys, in which the South Meadows and Keene lakes were formed, their drainage being west and south respectively. The altitudes were maintained as long as the ice covered every other possible outlet. At a later period a lower outlet was found when the ice left the northern slopes of Ampersand Mountain, allowing the drainage to pass to the west. Both the above-mentioned lakes were then united in the Newman Lake, with the Wilmington Notch acting as the connecting link.

The Saranac waters succeeded Lake Newman because of the opening of lower outlet channels, probably in the Black Mountain Pass, with its side channels successively opened up by the retreating ice-lobes, thus lowering the Saranac level through many steps.

The first series of definite beaches, deltas, and terraces was furnished by Wilmington Lake in the eastern section of the region. The drainage of this lake was westward through the Gulf over a series of cataracts, and finally along the ice-lobes into the Hudson River Valley. The South Meadows area was drained through this same outlet.

Lake Wilmington was succeeded by a number of other glacial lakes, because of the unusual topography, which, as the ice retreated, opened up a succession of outlets at lower levels, the lowest of these levels being of marine origin, dating from the time when the Hudson-Champlain Strait connected the Champlain Sea with the Atlantic Ocean.

ELIZABETHTOWN GROUP

Commencing somewhat later in time, a series of events occurred in the Elizabethtown Valley similar to those which took place in Keene Valley. When better known, the history of this succession of lakes promises to be just as dramatic and interesting as that of the other series, for a glacial lake origin is now assigned to many of the terraces that geologists formerly attributed to the temporary holding back of drainage waters by moraines. Apparently the Elizabethtown group of lakes succeeded each other with such rapidity that they passed out of existence by the time the latter stages of the Saranac Waters drained through the Black Mountain channels. It is probable that the Wilmington Lake discharged through the Copperas Pond channel directly into the marine waters.

Post-Lacustrine Deformation

GENERAL DISCUSSION

It has been pointed out that at the maximum extent of the Wisconsin ice-body the load on the land surface must have been tremendous. This weight compressed the land below its former level, which consequently rose when the load was removed by the retreat of the glacier. As these glacial lakes existed during the waning of the ice-sheet, the succession of terraces, deltas, and beaches form today a series with altitudes slightly rising to the north. The measurement of the amount of deformation has been attempted for a number of the different lake levels. The work of Professors Woodworth and Fairchild in the Connecticut and the Champlain-Hudson valleys has greatly cleared up our conceptions regarding Pleistocene submergence and postglacial deformation.

At the same time there exists some uncertainty as to the character of the uplift. (1) Was the upward movement gradual and uniform or (2) was it in the nature of a wave or a series of sudden uplifts? I believe that the problem will be greatly clarified by accurate measurements of beaches, deltas, etcetera, situated at higher levels to supplement those mapped at lower altitudes. The shore phenomena of the lakes above described afford a splendid opportunity to determine the amount of deformation of the land surface, for they give us a series of datum planes higher than those in the Champlain Valley, which was occupied by ice during the entire period that covered the existence of the various lakes above described.

A glance at the table given below would indicate that the uplift followed very soon after the retreat of the ice and was a uniform and gradual process during the time represented by the lakes.

DEFORMATION CHART FOR THE KEENE VALLEY GROUP

Lake	Altitude	Calculated deformation—feet per mile
South Meadows	2,000–2,040	....
Keene Lake	2,000–2,040	About 3.
Newman Lake	1,740–1,875	....
Saranac waters	1,450–1,600	....
Saint Hubert Lake	About 1,300+	....
Wilmington Lake	1,100–1,140	3.09 2.94
Upper Jay Lake	1,000	2.79
Haselton Lake	960	2.63
Lower Jay Lake	940	....
Otis Lake	900	....
Rocky Branch Lake	860	....
Clifford Lake	840	2.60
Styles Lake	820–825	....
Wainright Lake	760–770	2.00 (?)

Although too much stress should not be put on the accuracy of the figures given, they would seem to indicate, nevertheless, that the datum planes for the lakes differed slightly in every case, higher lakes showing a deformation slightly greater than those of lower altitudes.

EXPLANATION OF CHART

Following the lead of Professor Woodworth,[21] the writer has attempted to give, by means of the accompanying chart, the relative positions of the important terraces, deltas, and beaches which have been cited in establishing the glacial lake succession of the lower series in the Keene Valley group.

The chart is essentially a north and south plane on which the shoreline phenomena of the different lakes situated in the Lake Placid and Ausable quadrangles have been projected. It clearly shows that the datum planes of the lakes rise to the north, and that each plane has a somewhat different gradient, the higher lakes having the steeper slope.

Professor Fairchild has suggested that the datum plane lines should not have been drawn through the actual bed surfaces of the outlet spillways, as this leaves out of consideration the depth of water. Such a change would make the chart more accurate. If the datum planes are parallel, as Professor Fairchild believes, it would be necessary to increase the depth of the water flowing over the spillways as we descend to the glacial lakes of lower altitudes.

Any satisfactory conclusion must wait until the altitudes of the shore phenomena are very carefully measured.

[21] J. B. Woodworth: Ancient water levels of the Champlain and Hudson valleys. N. Y. State Mus. Bull., No. 84, pl. 28.

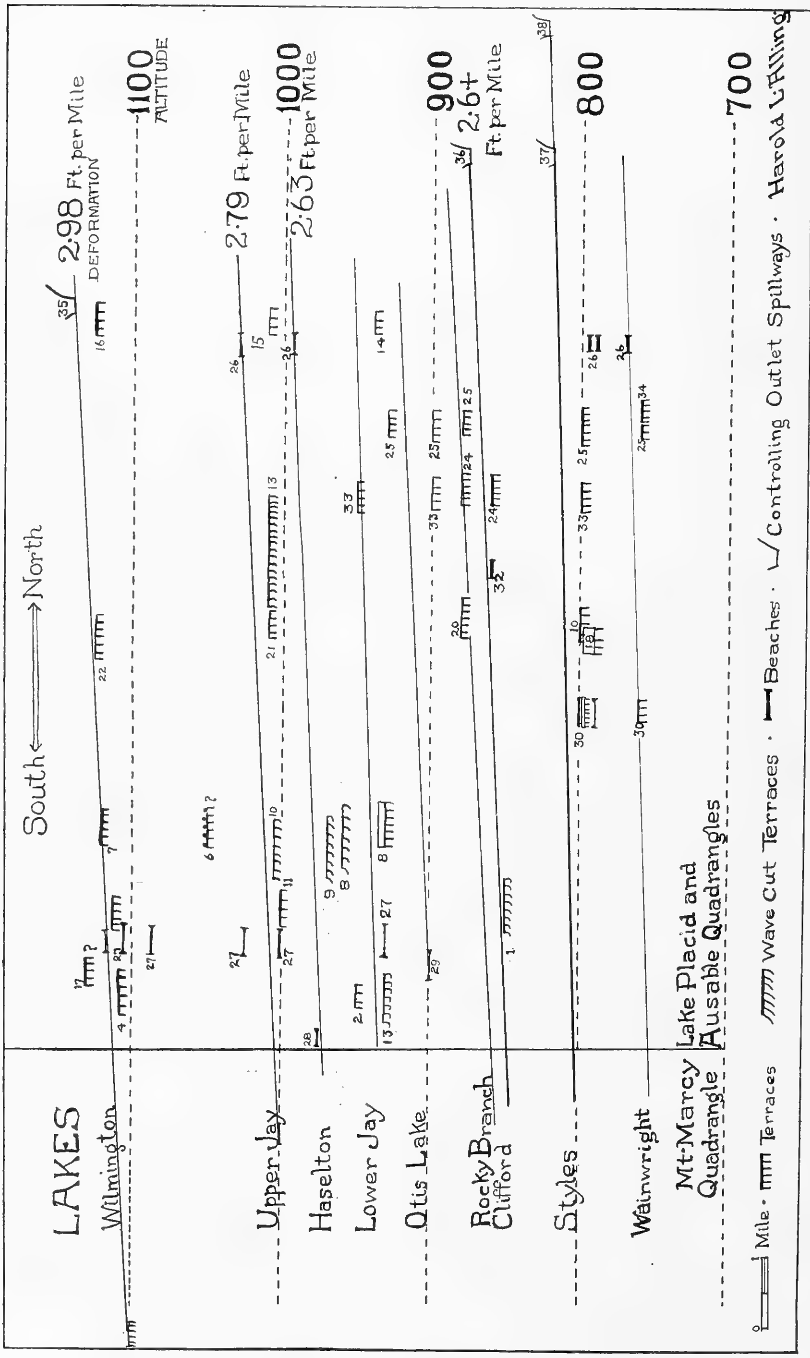


FIGURE 2.—*Preliminary Profile of glacial Lake Levels in Lake Placid and Ausable Quadrangles*

INDEX TO CHART

1.	Terrace	840	One and a half miles north of Keene, where Clifford Branch empties into the Ausable.
2.	Bottom	950	Keene cemetery, ¼ mile south of Keene.
3.	Terrace	930 1,000	One-fourth mile south of Keene.
4.	Terrace	1,112	One mile northeast of Keene.
5.	Terraces	925 930 1,000	Three miles south of Upper Jay.
6.	Terraces	1,050	Bouldery surface, 3⅛ miles south of Upper Jay.
7.	Terraces	1,120	Wilmington Lake, 3⅛ miles south of Upper Jay.
8.	Terrace	960	Two and a half miles north of Keene.
9.	Terrace	930, approx.	Five-eighths mile north of "Red" of Red Brook.
10.	Terrace	1,005	One-half mile south of Keene.
11.	Terrace	1,000	One and three-quarter miles north-northeast of Keene.
12.	Terrace	1,113	Wilmington Lake, 1¾ miles north-northeast of Keene.
13.	Terrace	1,010+	One and a half miles north of Upper Jay.
14.	Terraces	940	Five-eighths mile west of Wilmington.
15. 16.		1,010 1,125	Wilmington.
17.	Terrace	930 1,000 1,350	Three-fourths mile north-northeast of Keene.
18.	Terrace	790–800	One mile north of Upper Jay.
19. 20. 21.	Terrace	800 880 1,000+	One mile east of Upper Jay.
22.	Terraces	1,125–1,130	One and a quarter miles north of Clements Mountain.
23.	Terrace	1,145	Two miles southeast of Lower Jay.
24.	Terrace	860–880	One and a half miles south-southeast of Lower Jay.
25.	Terrace Range	930–900–880–800–760 without much separation.	Lower Jay, west of river.
26.	Beaches	1,030 994 795 (770)	On slope of hill, 1¾ miles northeast of Lower Jay.
27.	Beaches	960 1,000 (996) 1,027 (1,023) 1,087 (1,082) 1,105 1,117	One-half mile north of Keene.
28.	Beaches	934 976	Near Keene, ⅛ mile south.

28. Wavecut terraces	935 .... 977	Near Keene, ⅛ mile south.
28. Wavecut terraces	933½ 976	Near Keene, ⅛ mile south.
29. Beach	900	One and a half miles northeast of Keene.
30. Terrace	760 .... 800	One and five-eighths miles south of Upper Jay.
31. Beaches	790 .... 798	One-fourth mile southeast of Upper Jay.
32. Beaches	860	Five-eighths mile northwest of Upper Jay.
33. Beaches	800, approx. 900 .... 950	One mile northeast of Upper Jay.
34. Terrace	760	Three-fourths mile southeast of Lower Jay.
35. Outlet	1,140	The Gulf, Wilmington Lake.
36. Outlet	870	One-half mile south of Ragged Mountain.
37. Outlet	820	East of Bald Mountain.
38. Outlet	825	Two and three-quarter miles south of Ferrona.

Postscript

Between the time of handing the manuscript to the Secretary of the Society and the receiving of the proof a field season has intervened, affording an opportunity to further investigate the different levels, and as a consequence a number of changes should be noted.

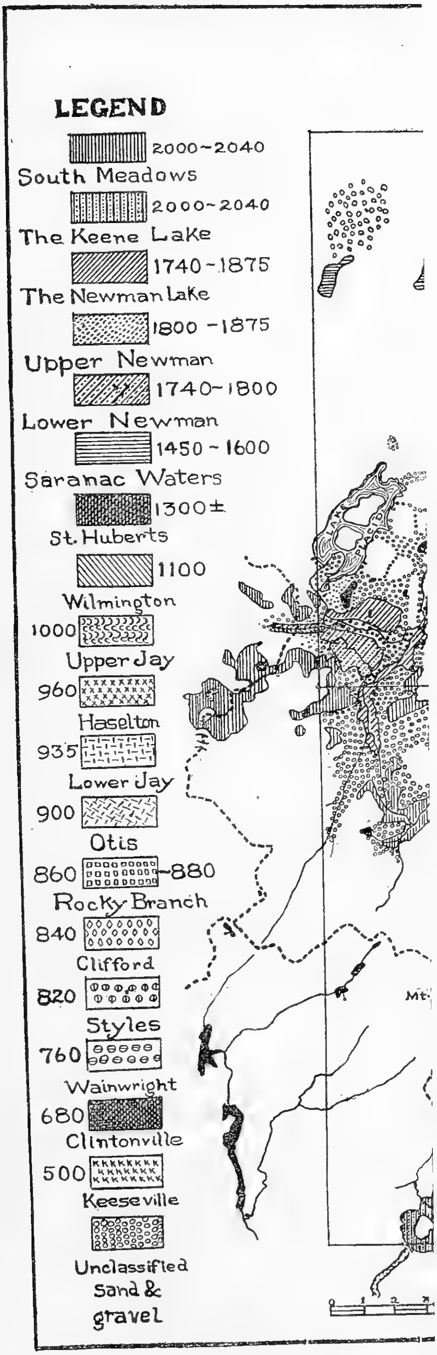
The altitudes of the glacial lakes have been rechecked; the important changes are as follows: The South Meadows, from 2,000-2,040 to 1,950-2,210 feet. The last figure is based on a splendidly developed beach that establishes the glacial nature of this level. Newman Lake, from 1,740-1,875 to 1,740-1,895 feet, especially in the Saranac quadrangle. The Saranac glacial water levels, from 1,450-1,600 feet to 1,440-1,660 feet.

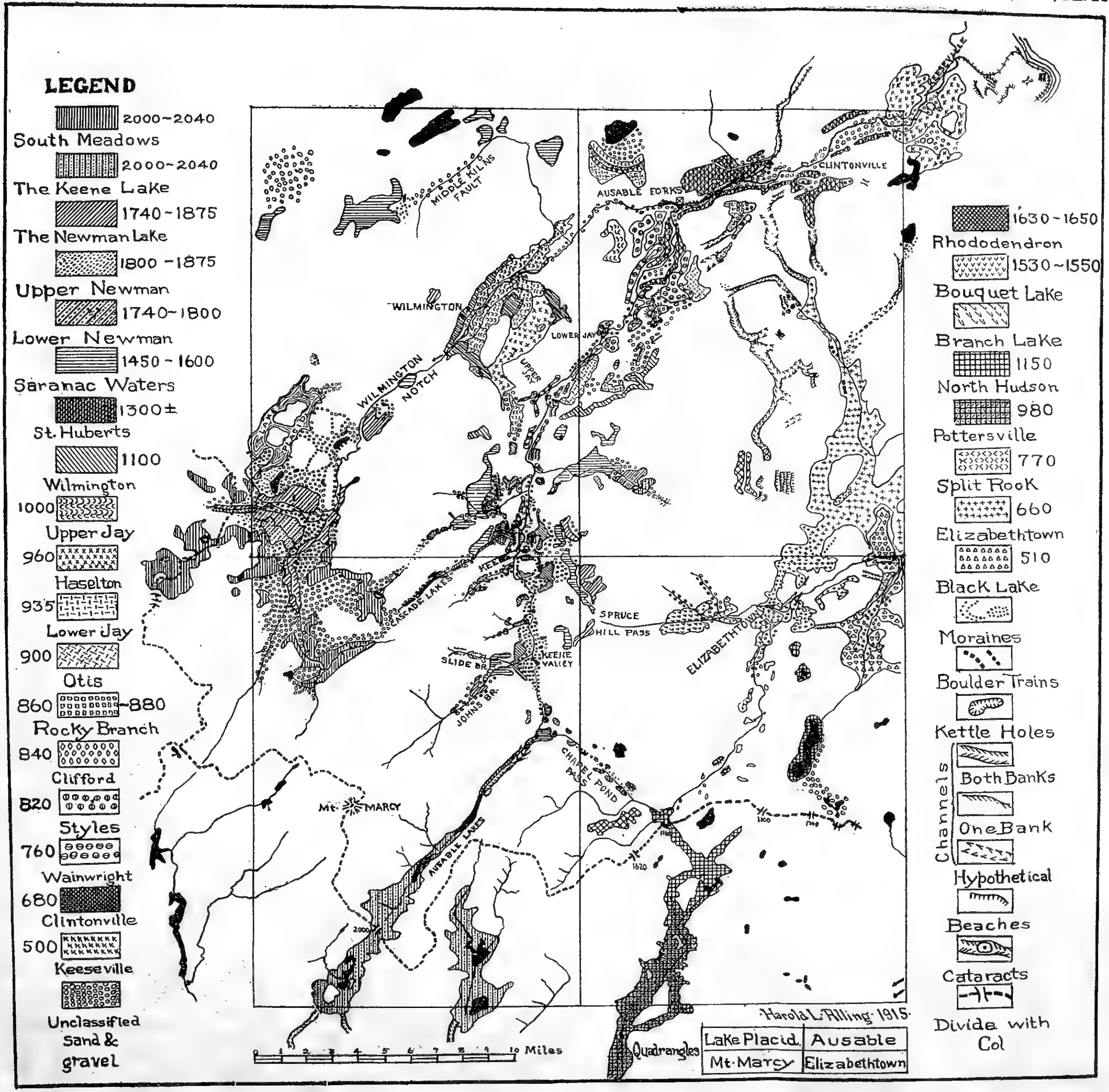
The glacial character of the lower series of lakes in Keene Valley, from the "Otis" down to the "Wainwright" levels, inclusive (altitudes, 900, 860-880, 840, 820-825, and 760 feet), is now being questioned. Some of the "beaches" are undoubtedly stream meander terraces and scarps, while others are lake-shore features. Until distinctions in the important cases can be made the nature of these levels must be left as an open question.

The Elizabethtown Lake, first regarded as a morainal lake by Doctor Ries and a glacial lake by the writer, appears to be marine in origin. Its altitude is now given at about 600 feet instead of 660, and now it ties in with the Clintonville level at 647, which was recorded as 680 feet.

Dr. D. W. Johnson has rendered great service to the writer in problem of local glaciation. We found in the cirque on the eastern slopes of Esther Mountain a lateral moraine of unmistakable local origin, and, together with other cirques and hanging valleys, the writer has become convinced that the Adirondacks supported local glaciers.

November 13, 1916.


LEGEND
2000~2040
South Meadows
2000~2040
The Keene Lake
1740~1875
The Newman Lake
1800 -1875
Upper Newman
1740~1800
Lower Newman
1450~1600
Saranac Waters
1300±
St. Huberts
1100
Wilmington
1000
Upper Jay
960
Haselton
935
Lower Jay
900
Otis
860 -880
Rocky Branch
840
Clifford
820
Styles
760
Wainwright
680
Clintonville
500
Keeseville
Unclassified Sand & gravel
LAKE PLACID
Mt.



GLACIAL WATERS IN THE CENTRAL ADIRONDACKS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 27, PP. 673-684 DECEMBER 9, 1916

CRETACEOUS OF ALBERTA, CANADA [1]

BY JOSEPH H. SINCLAIR

(*Read before the Society December 30, 1915*)

CONTENTS

Introduction

During the summer of 1914 the writer of this paper had the occasion to visit the foothill district of Alberta, Canada, and by means of traverses of the consequent streams which cut across the upturned strata at right angles to their trend succeeded in obtaining some geological data which, although incomplete, it is hoped will be of service to future investigators in this field.

The District studied

The district described lies between the abrupt eastward facing escarpment of the Lewis thrust-fault of the Rocky Mountains and the horizontal strata of the Great Plains. It is called the foothill district. The portion of this semi-mountainous area treated here lies southwest of the city of Calgary and is a narrow strip of country about 15 miles wide and 70

[1] Manuscript received by the Secretary of the Society February 15, 1916.

miles long, bounded on the north by the Bow River and on the south by the North Fork of Willow Creek.

Physiographic Features

The physiographic features are of the characteristic foothill type so well known in Colorado and elsewhere. Long hog-back ridges, remarkably straight, trending nearly north and south and parallel to the Rocky Mountain escarpment, are associated with narrow valleys in which an inactive subsequent drainage is witnessed by the presence of small streams, small lakes in places, and swampy areas. The former are defined by the uptilting of hard sandstone strata; the latter by the easily disintegrated weak shales, entirely of the Benton formation.

A characteristic feature also are the consequent streams, which, rising in the Rocky Mountains to the west, have cut notches in the hog-backs and, flowing directly across the district at right angles to the strike of the strata, debouch on the plains to the east. These, in order from north to south, are the Bow River, Sheep River, Highwood River, and Willow Creek. They debouch into the plains at an average elevation of 3,200 feet, the average elevation of the hog-backs being about 4,000 feet above the sea.

General Character of the Strata

The rocks of this narrow belt are almost entirely of Cretaceous age, bounded on the west by the Paleozoic massive limestones of the Livingston Range of the Rockies and on the east by flat-lying sediments of Tertiary age. Curiously enough, the three epochs represent three distinct types of structure which, as indicated above, are represented by three distinct types of land forms. The Paleozoic strata bounding the foothills on the west are great blocks of hard and massive limestones shoved over the Cretaceous strata, en bloc, it might be said, and their lofty summits attain elevations of 6,000 to 8,000 feet above the sea. The Cretaceous sediments are composed of sandstones and shales contorted, overturned, and faulted to a remarkably confusing degree. The Tertiary strata to the east are flat lying, and there does not appear to be any appreciable lessening of the complicated folding as one approaches these massive flat-lying Tertiary rocks. The transition is abrupt. On one side a maze of folds, a zone of broken and faulted rocks, and suddenly the gently dipping and flat-lying Tertiary strata are met with. The Paleozoic rocks are mountains; the Cretaceous form foothills; the Tertiary, prairies.

It can be imagined that the working out of the geological succession of this foothill region has been no simple problem. The great areas mapped

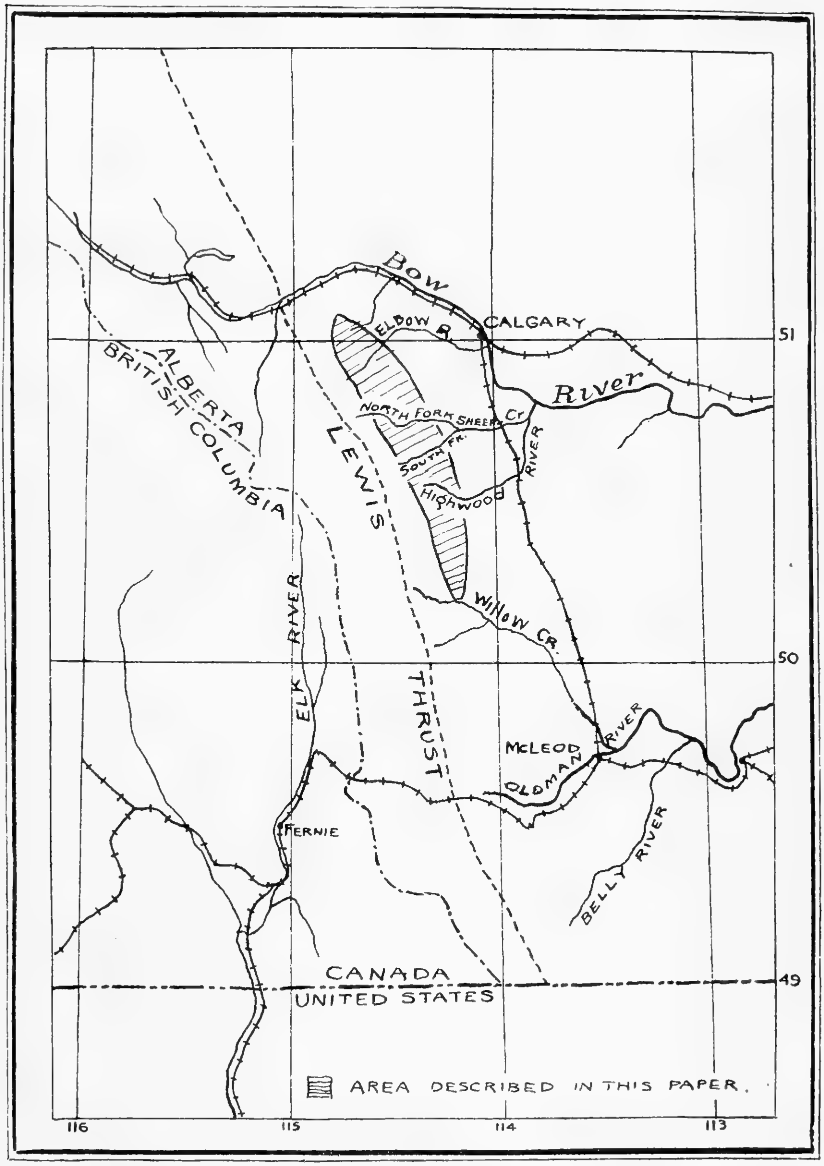


FIGURE 1.—*Part of Alberta and British Columbia*

by the pioneer geologists of the Geological Survey of Canada permitted only the working out of the general succession of strata, and it was early

seen that there was a certain resemblance here to the famous Cretaceous section of the Upper Missouri River in Montana.

About 1907 Cairnes, of the Geological Survey of Canada, took up in detail the mapping of about 1,500 square miles, located 25 miles southwest of Calgary, and was successful in recognizing the presence of formations unquestionably identical with some of the formations of the Upper Missouri River. The finding of part of the Upper Missouri section led to the adoption of the whole, and this recently has been found to call for certain modifications.

The succession for the Elbow River and Sheep River as worked out by Cairnes and generally accepted, in 1914, is as follows:

TERTIARY.	Paskapoo formation.	Sandstones.
CRETACEOUS.	Edmonton formation.	Sandstones.
	Bearpaw formation.	Marine shales.
	Belly River formation.	Sandstones.
	Claggett-Benton formation.	Marine shales.
	Dakota formation.	Sandstones.
	Kootenay formation.	Sandstones.
JURASSIC.	Fernie shales.	Marine shales.
DEVONO-CARBONIFEROUS.	Not subdivided.	Limestones.

This was the succession as defined by D. D. Cairnes in his paper, "Moose Mountain district of southern Alberta," Geological Survey of Canada, 1907.

At the time of the visit of the writer of the present paper, in 1914, Mr. D. B. Dowling and Mr. S. E. Slipper, of the Geological Survey of Canada, were engaged in a detailed study of the area adjoining Cairnes' district, and simultaneously with the author recognized the necessity for certain modifications of the previously accepted column.

In order to understand the geology of this district, it is as well to follow Cairnes' method and, beginning with his lowest formation, discuss in turn the various formations from the oldest to the most recent. In this way the facts on which the present paper is based may be more clearly presented.

Cairnes began his detailed classification at the top of a thick, massive series of limestones which he did not attempt to study closely and which he grouped under the general name "Devono-Carboniferous." This basal group is seen in but a small corner of his area and the area discussed in this paper. Southward, both on the Moose Mountain area and in the district described in the present paper, the Lewis thrust has caused the concealment by these massive limestones of the Fernie shales, Kootenay,

and in places farther south all the Cretaceous up to the Belly River formation. This basal group of unclassified limestones may serve also, for this discussion, as a starting point to describe the overlying Jurassic and Cretaceous formations, since it marks the transition from a great thickness of limestones to a great group of shales and sandstones.

Fernie Shales

The first of the formations overlying the Devono-Carboniferous limestones was correlated by Cairnes with the Fernie shales. This formation received its name from the type locality near Fernie, British Columbia, where it varies from a thickness of 650 to 3,000 feet. In the Banff area, west of Calgary, on the Bow River, it is assigned a thickness of 1,400 feet. Cairnes, on the Elbow River, worked out a thickness of 315 feet, which has been checked by the author on the Elbow River at the south end of Moose Mountain.

In the Bow River section, near Banff, Alberta, the Fernie shales are described by various writers as resting on a formation called the Upper Banff shales—a brown, calcareous and arenaceous formation, with interbedded thin layers of sandstone. This formation has been generally accepted as Permian in age, but recently this has been questioned. Whatever its exact age may be, it appears to be reasonably certain that there was a long interval between the deposition of the Upper Banff shale and the Fernie shale, which is generally accepted as Upper Jurassic in age.

Cairnes correlated the shales on the Elbow River with the Fernie shales on some paleontological evidence and from their position below a formation which was clearly of Kootenay age.

It is probable, from the varying thicknesses given above of the Fernie shales, the general overlap relations, and the unconformity between the Fernie shales and the Upper Banff shales in the Bow River Valley, that a marked unconformity also exists at the base of the Fernie shales on the Elbow River.

Kootenay Formation

This formation, the great coal-bearing series of the Crowsnest Pass, received its name also from the type locality near Fernie, British Columbia. It is formed everywhere of brackish and fresh-water sediments. In the type locality the earliest strata of this formation have developed a flora of Jurassic characteristics, and these beds are generally regarded as at least not younger than Middle Comanchean.

In the Crowsnest region and elsewhere a flora of about 85 species is known from the Kootenay formation. This includes no flowering plants, the forms present consisting mainly of ferns (34 species), cycads (19 species), and conifers (25 species).

Lithologically the formation is composed of sandstones, with important beds of coal, which are very persistent over a wide area in Alberta and British Columbia. It attains a maximum of 5,300 feet thickness in the Crowsnest district, and in the Banff area it is described as having thickness of about 4,300 feet. The latter figure, however, includes the lower Ribboned sandstone and the upper Ribboned sandstone, barren portions of the Kootenay above and below the coal measures. In the Elbow River area Cairnes and the author of this paper agree in a thickness of only 315 feet. This unquestionably marks the eastward extension of the Kootenay basin.

Blairmore Formation

Overlying the Kootenay sandstones and similar lithologically is a thick series of sandstones which were correlated by Cairnes with the Dakota sandstones south of the United States boundary. Farther south, in the Crowsnest district of Alberta, the name "Blairmore" has been adopted for a group of sandstones which are found at the same horizon as those on the Elbow River—that is, overlying the undoubtedly Kootenay formation. Inasmuch as the Dakota sandstone is not now recognized anywhere in the State of Montana, and as there is neither lithologic nor paleontological evidence to justify identifying the Blairmore with the Dakota formation elsewhere, it seems more fitting to the author of this paper that the name Blairmore should be applied generally to the formation on Sheep River and Elbow River which had been named Dakota by Cairnes.

As has been said above, there is no lithologic difference between the sandstones of the Kootenay and those of the Blairmore which overlie it, nor is there sufficient difference in the plant remains to justify separating the series into these two groups. Since, however, a persistent conglomerate bed from 8 to 15 feet thick is everywhere found overlying the coals of the Kootenay formation, it may be as well to accept the upper portion of this sandstone group as a separate formation, with the name Blairmore.

Measurements made by the author on the Elbow River and on the North Fork of Sheep River, where the entire formation is clearly exposed, have resulted in the finding of a thickness of 1,700 feet. This is from the top of the conglomerate horizon to the base of the Benton shales.

The Blairmore formation all through the foothill region is composed of yellowish, massive sandstones in the bottom portion, which upward be-

come greenish and light colored. Cairnes succeeded in finding a few plant remains, but in general the formation is remarkably barren of fossils.

Benton Formation

The change from the Kootenay-Blairmore continental conditions to the marine Benton is sharply marked all through the foothills. Everywhere the contrast between the greenish shaly sandstones of the Blairmore and the black, thinly laminated bituminous shales of the Benton is noticeable. The same is true of the upper line between the Benton and the Belly River formation. The folding of the massive sandstones of the Blairmore and Belly River formations is intensified to an extraordinary degree in the weak shales of the included Benton, causing a very complex mass of distorted strata whose thickness is extremely difficult of measurement. From many traverses on all the streams of the region, together with the logs of oil wells, it has been possible to compute the thickness of these shales as 2,400 feet. The formation is remarkably uniform in character, varied here and there by thin calcareous bands never exceeding one foot in thickness, and by oval-shaped ironstone nodules of small diameter. There is a thin sandstone and conglomerate horizon in the northern part of the district, which there attains a thickness of nearly 10 feet and has been named the "Cardium" sandstone by early writers on account of the presence of *Cardium pauperculum* in considerable numbers. The Cardium horizon, however, is only of local extent near the Bow River and on the Elbow River. Cairnes had used this as a line of separation of the shale group into two formations, the portion above the Cardium horizon being called Claggett and that below being named Benton. The exploration of the Benton shales, however, by the author of this paper has repeatedly resulted in the finding of typical Benton forms at the very top of the shale group or at the top of Cairnes' Claggett, underlying the sandstone strata of the Belly River formation. The Geological Survey of Canada has of recent years doubted the presence of the Claggett anywhere in the foothills, and the data of this paper bears out this conclusion.

Of all the Cretaceous formations in the area described in this paper the Benton formation is the most certain. It is unquestionably the equivalent of the Colorado shale of the United States.

Collections of the fauna were made from the various localities shown in the appended statement. Thanks to Mr. H. R. Johnson, of Los Angeles, California, and to Dr. J. P. Smith, of Leland Stanford University, it is possible to publish this list. The following species have been identified as Benton by Dr. Smith:

Inoceramus deformis Meek.
exogyroides M. & H.
gilberti White.
labiatus (Schlotheim).
undabundus M. & H.
umbonatus M. & H.
fragilis H. & M.
simpsoni Meek.
Ostrea congesta Conrad.
Pecten sp. nov. ? x.
Scaphites ventricosus M. & H.
warreni M. & H.
vermiformis M. & H.
conf. larviformis M. & H.
Baculites asper Morton.
gracilis Shumard.
Pholadomya papyracea M. & H.
Cardium pauperculum Meek.
Cyrena securis Meek.
Volutoderma ambigua (Stanton).
Prionocyclus wyomingensis Meek.

The following list shows in detail the forms collected by localities:

Jumpingpound Creek, near Nichol's ranch........................ *Benton.*

Inoceramus labiatus (Schlotheim).
deformis Meek.
undabundus M. & H.
exogyroides M. & H.
fragilis H. & M.
gilberti White.
umbonatus M. & H.
Ostrea congesta Conrad.
Pecten sp. nov. ? x.
Scaphites ventricosus M. & H.
warreni M. & H.
Baculites asper Morton.
gracilis Shumard.

South Fork of Sheep Creek, near Dingman well.................... *Benton.*

Inoceramus deformis Meek.
exogyroides M. & H.
gilberti White.
labiatus (Schlotheim).
Ostrea congesta Conrad.
Pecten nov. sp. x.
Pholadomya papyracea M. & H.
Cardium pauperculum Meek.

Cyrena securis Meek.
Volutoderma ambigua (Stanton).
Scaphites ventricosus M. & H.
vermiformis M. & H.
conf. larviformis M. & H.
Baculites asper Morton.
conf. gracilis Shumard.

Highwood River, near Ing's and Pocaterra's ranches, mouth of Sullivan Creek and Trap Creek.................................... *Benton.*

Inoceramus simpsoni Meek.
exogyroides M. & H.
gilberti White.
Pecten sp. nov. x.
Scaphites ventricosus M. & H.
vermiformis M. & H.
Baculites asper Morton.
Prionocyclus wyomingensis Meek.

North Fork of Willow Creek, near Dick's ranch.................. *Benton.*

Inoceramus labiatus (Schlotheim).
deformis Meek.
simpsoni Meek.
exogyroides M. & H.
Pecten sp. nov. x.
Ostrea congesta Conrad.
Scaphites vermiformis M. & H.
Baculites gracilis ? Shumard.
asper Morton.

The large majority of the species collected from the Benton formation are Upper Colorado forms. A few species, such as *Inoceramus labiatus* (Schlotheim), *Prionocyclus wyomingensis* Meek, *Scaphites warreni* M. & H., and *Volutoderma ambigua* (Stanton), indicate lower horizons. It is regrettable that the exact stratigraphic position in the Benton formation can not be given for each lot of fossils listed. The repeated faulting and complex folding make this a detailed work calling for more time than was available for this work.

Belly River Formation

As far as the Sheep River, the Elbow River, and the rest of our area is concerned, it is difficult to subdivide the sediments above the Benton formation. These rocks are a great development of brackish and freshwater sandstones of uncertain thickness. In part they represent the westward boundary of marine basins, such as the Bearpaw. The separation,

therefore, into Belly River formation, Bearpaw formation, Edmonton formation, and Paskapoo formation is a difficult matter, since the rocks are lithologically the same and no fossils have as yet been found to assist in defining any time horizons. The formation immediately overlying the Benton shales has been called here the Belly River formation from its stratigraphic position. In the Great Plains region, especially along the Red Deer River and southward near the International Boundary, the Belly River formation is noted for the remains of dinosaurs and invertebrate fossils, which have clearly correlated the formation in part with the Judith River formation of the Upper Missouri River; but, as above stated, no fossils have been found in what is believed to be the Belly River formation in the area discussed in this paper. Its thickness and recognition are not as yet entirely certain. In the Sheep River district, however, there is a thickness of 1,400 feet of light-colored sandstones which can be grouped as a formation, due to the fact that the upper portion is defined or bounded by a zone of weak rocks with coal beds. This horizon is shown in the rocks and coal seam at McPherson's coal mine, near Black Diamond post-office, on the North Fork of Sheep Creek, and also in the strata at the old McDougall coal mine west and farther up the creek, near Linehan post-office. On the Highwood River this coal horizon is also recognized and in several places small mines are located for the mining of coal. It is a characteristic zone, noted by a high degree of folding and faulting. It probably is not over a hundred feet in thickness, but everywhere it stands out from the overlying and underlying massive and unbroken and unfolded sandstones.

Bearpaw Formation

The Bearpaw formation unquestionably exists in the Great Plains region to the east of the foothills. Fossils have been collected by the writer of this paper in the Battle River district which are undoubted Bearpaw types. But although very careful search has been made on Sheep River and other streams of this district, no fossils have been found of the Bearpaw horizon, nor have any shales been met with which could be classified as Bearpaw. Although Mr. Dowling speaks of the Bearpaw as a marine deposit in a somewhat diminished form in the foothills farther south, the writer of this paper believes that it does not exist as a marine deposit north of Willow Creek and south of the Bow River. It is of course possible that a small thickness of the Bearpaw may be hidden in the faulting so characteristic of the coal horizon taken above as the upper limit of the Belly River formation. Cairnes has mapped portions of his area as Bear-

paw or Upper Pierre. He evidently confused portions of the Benton formation with the Bearpaw.

Edmonton Formation

This formation is described by Canadian geologists as the upper limit of the Cretaceous in western Canada. In the north of Alberta, in its type locality near Edmonton, the formation is noted for coal seams of a sub-bituminous nature. Its upper limit is rather vaguely described, so

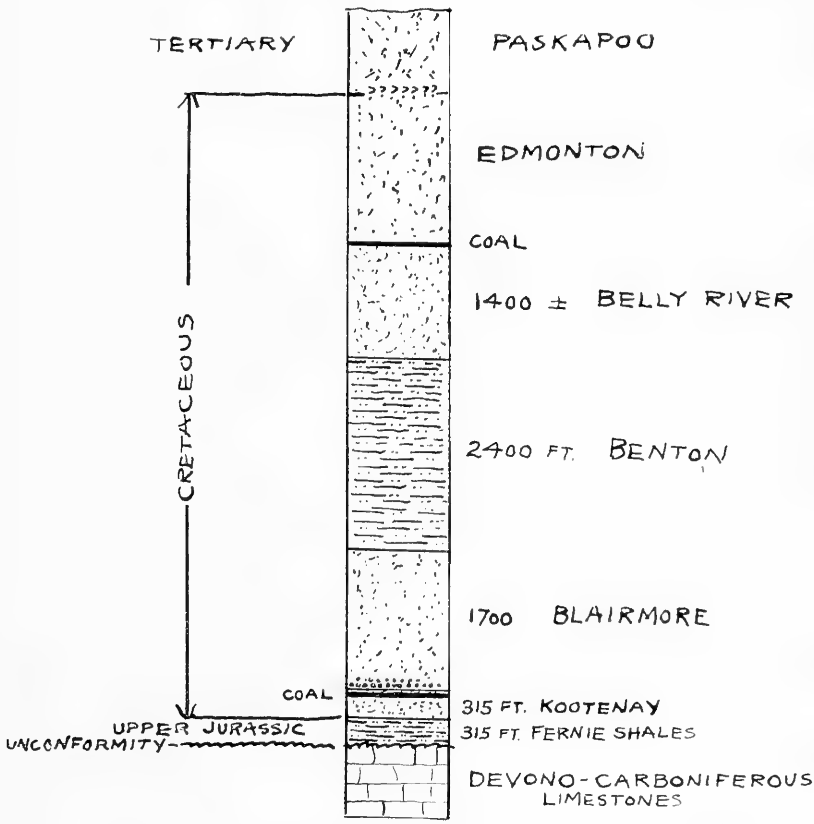


Figure 2.—*Cretaceous Sedimentation in the Alberta District of Canada*

that the writer of this paper has never been certain of where the boundary line should be taken between the Edmonton formation and the Paskapoo formation or between the Cretaceous and Tertiary. In the region herewith described there is a continuous series of light-colored sandstones

above the coal horizon which has been taken as the upper limit of the Belly River formation. No basis of subdivision of these Edmonton-Paskapoo sandstones is recognized either from the lithological point of view or the paleontological. Perhaps later detailed work may result in the finding of some paleontological evidence by which the Edmonton and Paskapoo can be demarked in the foothill region.

In conclusion, of the Cretaceous sediments of this area the following measurements and the following formations appear certain:

	Feet
Benton	2,400
Blairmore	1,700
Kootenay	315
	4,415

Taking into account the mass of unsubdivided sandstones above the Benton formation, and especially the Belly River formation, which is estimated at 1,400 feet thickness, it is safe to conclude a thickness of over 7,000 feet of Cretaceous sediments in this district.

The process of sedimentation in this area may be expressed graphically in figure 2, page 683.

Summary

The essential points of this paper may be summed up in the following statements:

1. Publication of a list of Benton fossils identified by Dr. J. P. Smith, of Leland Stanford University, and collected by a joint expedition financed by Mr. Harry R. Johnson, of Los Angeles, and the writer.

2. The bringing of evidence to prove the non-existence of the Bearpaw formation as a marine horizon in the foothills.

3. Corroboration of the non-existence of the Claggett formation as a distinct marine formation in the foothills. This fact was first definitely established south of the International Boundary, in 1914, by Stebinger, of the United States Geological Survey, and adequately presented in professional paper 90 G, "The Montana group of northwestern Montana," and about the same time it was confirmed by Dowling and others of the Canadian Geological Survey in Alberta.

4. Measurements involving thicknesses of the Blairmore formation and the Benton formation on the North Fork of Sheep River and on the Elbow River.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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TRIASSIC ROCKS OF ALASKA[1]

BY GEORGE C. MARTIN

(Presented in abstract before the Society December 30, 1915)

CONTENTS

[1] Published by permission of the Director of the U. S. Geological Survey.
European stratigraphic terms of lower than system rank are used in this paper for the purpose of indicating probable or possible correlations and without any intention of incorporating them into the American nomenclature.
Manuscript received by the Secretary of the Geological Society May 15, 1916.

Introduction

One of the most important results of the investigations by the United States Geological Survey in Alaska has been the discovery of thick sections of marine Triassic strata in many parts of the territory. These occurrences are of extreme interest and importance, not only because they constitute such a large and important part of the areal and stratigraphic geology of Alaska that an intimate knowledge of them is essential for a full understanding of the local geologic features, but because they show important relationships with the known sections in other regions, and because they will, when thoroughly studied, undoubtedly be found to constitute one of the most important, extensive, and complete sections of Upper Triassic rocks in North America, if not in the world. They will fill out the American stratigraphic column at points where it is very deficient in many other parts of the continent.

It has become evident that the rocks of Alaska offer very valuable contributions, not only to mineral wealth, but to pure science. In the acquisition of Alaska we received a European and Asiatic inheritance, both historically and geologically, for much of Alaska is essentially Russian in its geologic as well as in its human history. It is not a mere accident that the most elaborate publication on Alaskan fossils deals with faunas from the shores of both the Caspian Sea and of the Alaska Peninsula. It is perhaps a fortunate circumstance that the best of the early collections of Alaskan Jurassic ammonites are in Europe, where they are accessible for comparison with the closely related European and Asiatic forms. The lately terminated Russian dominion on the eastern shore of the North Pacific followed most fittingly after the often-repeated submergence of parts of both Alaska and Russia beneath a common sea in Triassic, as well as in Jurassic, Cretaceous, and Permian times.

Although no intensive stratigraphic and faunal studies of the Alaskan Triassic rocks have yet been undertaken, a very considerable volume of important stratigraphic data has already accumulated. These facts are partly unpublished and are partly scattered through a large number of reports on regional and economic geology, where they are not so accessible as they should be, nor is their volume and importance fully appreciated. There is need for a general preliminary discussion of these rocks, in order to call attention to the available data, to render it more accessible, and also, as far as possible, to coordinate the known facts, to present some important conclusions, and to call attention to some of the problems which further studies of the Alaskan rocks may help to solve or on which additional data from other regions are necessary for the solution of the Alaskan problems.

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as and tuffs, et. underlain oniferous (?) ne.	Ellip 3 Un slat wa kr

It was with this purpose that the writer presented to the Geological Society, four years ago (December, 1911), the outline[2] of a paper entitled "The mesozoic stratigraphy of Alaska." The work begun at that time has developed into a rather extensive and elaborate treatise on the Mesozoic rocks of Alaska, which, although primarily a summary of existing knowledge, is to a large degree based on special field investigations, the results of which have not hitherto been published. The studies mentioned above are now well toward completion, and the paper here presented includes some of the more important conclusions of general interest derived from the preparation of the Triassic chapter of that work.

Acknowledgments should be made to the many geologists, cited below, who made the field observations that are the basis of the descriptions here given, and also to Dr. T. W. Stanton, whose determinations of the fossils are the substantial basis of the conclusions here presented. It should be remembered that these field observations have been gathered, for the most part, in the course of pioneer reconnaissance investigations and necessarily are scanty and generalized. It should be remembered also that the fossils have not yet been exhaustively studied. The determinations of genera and species can be accepted as definite, except where a doubt is expressed; but no attempt has yet been made to list all the species, many of which are undescribed, or to determine the precise relations of the faunas to those of other regions. It is hardly necessary to add that the writer has based his interregional correlations largely on the published results of Prof. James Perrin Smith's elaborate studies and correlations of the Triassic rocks of California, Nevada, and Oregon. Professor Smith should not, however, be held responsible for the correlations of the Alaska and British Columbia rocks except where he is directly cited.

Description of the Triassic Rocks of Alaska[3]

OCCURRENCE AND GENERAL CHARACTER

Triassic rocks are widely distributed in Alaska, being now known at many localities (see map, plate 25) in nearly all parts of the three major mountain regions and being absolutely restricted thereto. The most striking fact regarding the distribution of Triassic rocks in Alaska is this remarkable agreement between the areas of present Triassic outcrops and the areas of the major mountain regions. In this respect conditions in Alaska are in accord with those in many other parts of the world. The marine Triassic is, with good reason, called the Alpine Trias, for in

[2] Bull. Geol. Soc. Am., vol. 23, 1912, pp. 724-725.

[3] In the local descriptive matter here presented, footnote reference will be given for only the latest or most comprehensive description of each formation.

Correlation of the Triassic Rocks in various parts of Alaska

Series	Stage	Nizina Valley.	Kotsina and Kuskulana valleys.	White River.	Cooper Pass.	Upper Susitna Valley.	Kenai Peninsula.	West coast of Cook Inlet.
Upper Triassic.	Upper Noric.	McCarthy formation (shale and thin limestones with Pseudomonotis subcircularis. Much chert in lower 1,000 ft.) Thickness, 1,500 to 2,000 feet. Conformity ?	McCarthy formation (black shales with thin limestones). Contains Pseudomonotis subcircularis. Thickness, 2,000 ? feet. Unconformity (?)	Lavas, tuffs, and breccias with Pseudomonotis. Shales with Pseudomonotis. Underlain unconformably by Permian (?) limestone.	Thin-bedded limestone with Pseudomonotis subcircularis. Thickness and relations not known.	Slate, tuff, arkose, and calcareous beds with Pseudomonotis subcircularis. Thickness many hundred feet.	Limestones with Pseudomonotis subcircularis near top and Halobia below. Thickness, 1,000 + feet.	Kamishak chert. Calcareous shale and some chert Contains Pseudomonotis subcircularis. Thickness, 1,000 ? feet.
Upper Triassic.							Contorted cherts. Thickness unknown.	Kamishak chert. Massive chert with no fossils. Thickness, 1,000 ? feet.
Upper Triassic.	Lower Noric.							Limestone with Halobia. Thickness and relations not known.
Upper Triassic.	Karnic or Noric.	Nizina limestone (thin-bedded limestone). No fossils. 1,000 to 1,200 feet. Conformity.	Thinly bedded limestones with some shales. Fauna similar to that of Chitistone limestone. Thickness, 500 to 3,000 feet.					
Upper Triassic.	Karnic.	Chitistone limestone. (Massive bluish-gray limestone. Contains Halobia cf. superba, Tropites, Juvavites, Arcestes, etc.) Thickness, 1,800 to 2,000 feet. Conformity ?	Chitistone limestone. (Massive limestone.) 300 to 1,200 ? feet. Conformity ?			Limestone with Halobia cf. superba, Tropites, etc. Thickness a few hundred feet.		
Upper Triassic.								
Middle Triassic.								
Permian (?) or Triassic.		Nikolai greenstone (basalt lavas). 4,000 to 5,000 feet. Base not exposed.	Nikolai greenstone. (Basalt lavas.) 6,500 ? ft. Underlain by Carboniferous beds.			Basic lavas and tuffs, 3,500 feet. Probably underlain by Carboniferous (?) limestone.	Ellipsoidal lavas. 3,000 feet. Underlain by slate and graywacke of unknown age.	Greenstone. Thickness and relations not known. Probably underlain by slate.

Series	Stage	Iliamna Lake.	Alaska Peninsula.	Kodiak Island.	Herring Bay, Admiralty Island.	Hamilton Bay, Kupreanof Island.	Gravina Island.	Yukon River near Nation River.
Upper Triassic.	Upper Noric.		Limestone and shale with Pseudomonotis subcircularis. Thickness, 700+ feet.			Cherty limestone with Pseudomonotis subcircularis. Basal conglomerate. Unconformity ?		Calcareous shale and shaly limestone with Pseudomonotis subcircularis. Conformity ?
Upper Triassic.			Contorted cherts, with no fossils Thickness not known.	Contorted cherts with no fossils. Thickness not known.	Cherts and shales with no fossils. Position doubtful.			
Upper Triassic.	Lower Noric.	Limestone with corals. Thickness several hundred feet.					Gravina formation. Shales with Halobia cf. superba. Limestone with corals. (Position and relations uncertain). Probably underlain by Devonian limestone.	
Upper Triassic.	Karnic or Noric.							
Upper Triassic.	Karnic.				Limestone with Halobia cf. superba, Juvavites, Arcestes, etc. Thickness, 273 feet. Basal contact not seen.	Cherty limestone with Halobia cf superba, etc. Relation to Dawsonites-bearing beds not known.		Limestones and shales with Halobia cf. superba and Clionites ? Basal limestone bed with many brachiopods, nautiloids, and Trachyceras cf. leconti. Thickness, 300 + feet. Underlain by Permian (?) limestone.
Upper Triassic.						Limestone float with Spiriferina borealis ? and Dawsonites canadense ?		
Middle Triassic.								
Permian (?) or Triassic.		Greenstone?	Greenstone.	Ellipsoidal lavas. Thickness unknown. Probably underlain by slate and graywacke		Ellipsoidal lavas. (Relations to Dawsonites-bearing beds not known.) Underlain by Permian (?) limestone.		

Series	Stage	Firth River.	Canning River.	Noatak Valley.	Cape Lisburne.	Cape Thompson.	Saint Lawrence Island.	Brooks Mountain, Seward Peninsula.
Upper Triassic.	Upper Noric.	Limestones with Pseudomonotis subcircularis. Thickness and relations unknown.	Float with Pseudomonotis subcircularis. Derivation uncertain.	Float of cherty limestone with Pseudomonotis subcircularis. Derivation not known.	Shales, cherts, and limestones with Pseudomonotis subcircularis; 1,000 + feet. Probably underlain by Carboniferous limestone.	Cherts and limestones with Pseudomonotis subcircularis; 625 ft. Underlain by Carboniferous ? limestone.	Float with Pseudomonotis subcircularis. Derivation uncertain.	
Upper Triassic.								
Upper Triassic.	Lower Noric.							
Upper Triassic.	Karnic or Noric.							
Upper Triassic.	Karnic.	Flaggy limestone with Halobia cf. superba. Thickness not known. Underlain by Permian (?) limestone.	Black shales with Halobia cf. superba. Limestone and some shale with Halobia cf. superba, brachiopods as at Nation River, Gervillia, Megalodon ? and Clionites ? Calcareous sandstone without characteristic fossils. Underlain by Permian (?) limestone.					
Upper Triassic.								
Middle Triassic.								Slates with Ceratites (Gymnotoceras) and Daonella. Thickness and relations not known.
Permian (?) or Triassic.								

Alaska, as in the Alps, in the Himalayas, and in the western part of the United States and of Canada it is generally, if not invariably, restricted to mountain regions of the Alpine (structural) type. The general world-wide geographic accordance of the present areas of marine Triassic rocks with mountains of Alpine form, structure, and date has previously been recognized, and has been stated by Frech[4] as follows:

"Scarcely in any period of the earth's history is the connection between the distribution of mountain zones and later sedimentation so clearly expressed as in the Trias.

"1. The provinces of the late Paleozoic folding correspond to the continental development of the Trias.

"2. The great Mediterranean sea of Eurasia and the margin of the Pacific Trias-ocean coincide with the zones of the Tertiary high mountains. Only the eastern margin of the Cordilleras (that is, the Rocky Mountains of North America, in a strict sense) contain a continental development of the Trias.

"3. The flat-lying Arctic Trias (Spitzbergen, North Siberia, Arctic (extra-Pacific) North America), where neither late Paleozoic nor Tertiary mountain building is encountered, can not be regarded as an exception to the above rule, but belongs, in a tectonic sense, to an indifferent province."

"The dependence of the distribution of the oceanic Trias on the later Alpine—that is to say, Eurasian and circumpacific—folding has been repeatedly emphasized, and means essentially that the accumulation of thick masses of sediments in the geosynclines determines the later folding. From northern Spain, the Balearics, Sicily, the Alps, and Dinarics to the Himalayas and Sumatra the same uniform law holds that also governs on the circumference of the Pacific Ocean. Here we see, also, from Alaska, Kamchatka, and Japan to New Caledonia, New Zealand, California, Mexico, Colombia, and Peru, the oceanic Trias constantly appearing in the provinces of Tertiary mountain building, which, without exception, are coincident with a great thickness of sediments."

The Alaskan instance is noteworthy not only because it is an additional example, but because the law holds there in such remarkable detail.

All the Triassic rocks of Alaska that are now known belong in the Upper Triassic, except for a single Middle Triassic occurrence on Seward Peninsula. It is probable that the Lower Triassic and much of the Middle Triassic are not represented in the Alaska rocks, except possibly by terrestrial volcanic rocks or by some metamorphosed strata of very doubtful age.

CHARACTER OF THE PRE-TRIASSIC BASEMENT

In general.—Before proceeding with the description and discussion of the known Triassic rocks of Alaska, it is important that we consider the character of the basement on which these beds were laid down.

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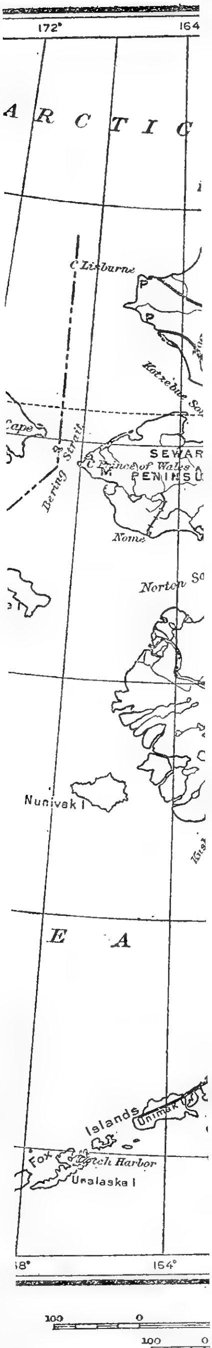
[4] Fritz Frech: Rückblick auf die Trias. Lethæa geognostica, Teil II, Bd. 1, Lieferung 4, 1908, pp. 510, 518.



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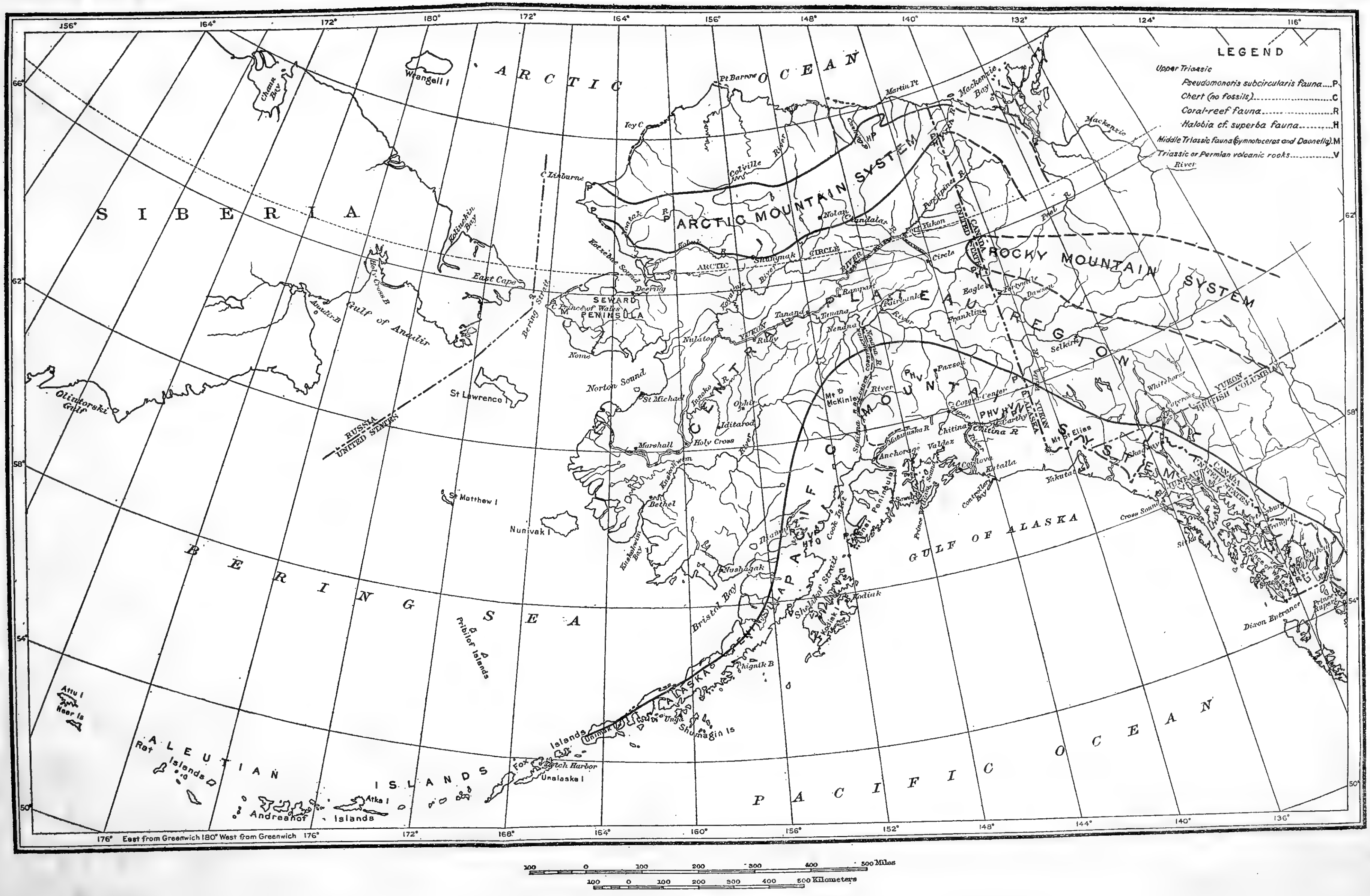

DISTRIBUTION OF ALASKA TRIASSIC FAUNAS

Permian (?) strata.—The youngest rocks of known age which underlie the Triassic beds of Alaska are early Permian (?) limestones. These limestones carry a fauna closely related to that of the Artinskian of Russia, which is regarded by some as pre-Permian, but which is more generally considered as the lowest division of the Permian. These Artinskian limestones are very widely distributed in Alaska, occurring in nearly all the larger geographic regions, and show that toward the close of the Paleozoic (at about the beginning of Permian time) limestone-forming seas extended over the larger part, if not all, of the area that is now Alaska. Marine Permian deposits younger than the Artinskian are not known and probably are not present in Alaska.

Pre-Triassic (?) slates of undetermined age.—Throughout most of the mountains on the Pacific coast of Alaska are large areas of slaty rocks of very uncertain age. The evidence on the age of these rocks is scanty and conflicting, and all that can be safely said concerning it is that they may be as old as early Paleozoic or as young as Upper Cretaceous. It is practically certain that these rocks are, at least in part, older than Upper Triassic, and the writer believes that they are, at least for the most part, Paleozoic. They clearly underlie the lavas that are beneath the Upper Triassic limestones and tuffs of the Kenai Peninsula (see page 697).

Early Triassic (?) volcanic rocks.—The Upper Triassic sedimentary rocks described below are underlain in many places throughout the Pacific Mountain belt by volcanic rocks that include both lavas and tuffs and that have in some places been described as greenstones. These rocks include the Nikolai greenstone of the Chitina Valley (see plate 26), the basic lavas and tuffs of the upper Susitna Valley, the ellipsoidal lavas of Kenai Peninsula and Kodiak Island, some of the greenstones of the Iliamna-Clark Lake district, and the ellipsoidal lavas of Hamilton Bay, in southeastern Alaska. In all these districts they clearly underlie the marine Upper Triassic strata without recognizable unconformity. It is only in the Chitina Valley that the basal contact of these rocks with underlying beds of known age has been observed. Here they rest on Carboniferous tuffs, cherts, and slates. In the Kenai Peninsula, on Kodiak Island, and probably on the west shore of Cook Inlet, they overlie the slaty rocks of unknown age that are described above. On Hamilton Bay they are probably underlain by lower Permian ? (Artinskian) limestones. These volcanic rocks may include also the greenstone of the Orca group of Prince William Sound, as well as part of the greenstones of southeastern Alaska. They may possibly be correlated with the lavas and tuffs beneath the Permian (?) limestone of White River, but it is more probable that they are either Permian or early Triassic.

MIDDLE TRIASSIC ROCKS

The only Middle Triassic rocks known in Alaska are some black slates occurring in the York Mountains, in the western part of Seward Peninsula. The geology at this locality is complex and obscure and has not been studied in detail. It is consequently impossible to describe the stratigraphic relations. All that is known[5] concerning the occurrence of Triassic rocks at this place is that some fossils which were given to E. M. Kindle, and which are said to have been obtained from black slates on Brooks Mountain that were previously considered as probably early Paleozoic, include *Daonella* cf. *lommeli* Wissman and an undetermined species of *Ceratites (Gymnotoceras)*.

UPPER TRIASSIC ROCKS

Chitina Valley (Wrangell Mountains).—The most complete section of Upper Triassic rocks in Alaska which is now known is in the Chitina Valley (see plate 26), where there are several thousand feet of marine Upper Triassic strata, mostly limestones and shales, resting with apparent conformity on a thick series of lavas, whose precise age has not been determined, but which are probably either Triassic or late Paleozoic (Permian ?). The sequence of Upper Triassic rocks in the eastern and western parts of the Chitina Valley is shown in the following sections:

General Section of Triassic Rocks in the Nizina Valley

	Feet
Upper Triassic:	
McCarthy formation (black shale, with a few thin beds of limestone and with much thin-bedded black chert at the base. Contains *Pseudomonotis subcircularis*)	1,500–2,500
(Conformity ?)	
Nizina limestone (thin-bedded limestone, becoming shaly toward the top). No fossils yet found	1,000–1,200
(Conformity.)	
Chitistone limestone (massive bluish gray limestone, with *Halobia* cf. *superba*, *Terebratula*, *Spiriferina*, *Tropites*, *Juvavites* (?), *Arcestes*, and *Atractites*)	1,800–2,000
(Conformity ?)	
Triassic or Permian:	
Nikolai greenstone (basaltic lava flows)	4,000–5,000
(Basal contact and underlying rocks not exposed.)	

General Section of Triassic Rocks in the Kotsina and Kuskulana Valleys

	Feet
Upper Triassic:	
McCarthy formation (black shales, with a few thin beds of limestone. Contains *Pseudomonotis subcircularis*)	2,000 ?

[5] E. M. Kindle: The faunal succession in the Port Clarence limestone, Alaska. Am. Jour. Sci., 4th ser., vol. 32, 1911, p. 329.

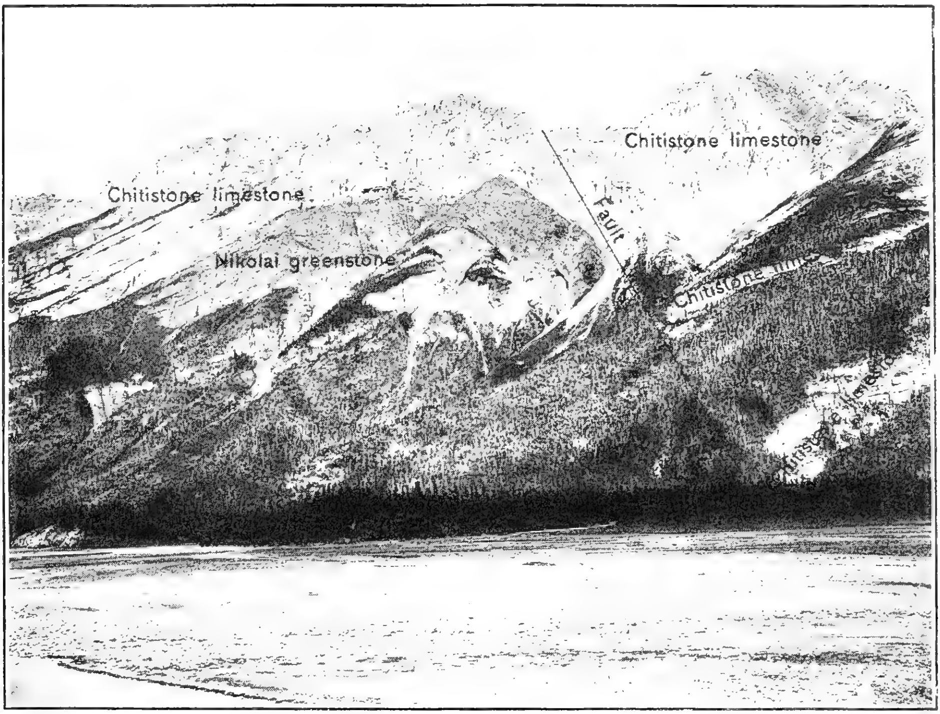

FIGURE 1.—CHITISTONE LIMESTONE AND NIKOLAI GREENSTONE NORTH SIDE CHITISTONE RIVER
Photograph by S. R. Capps

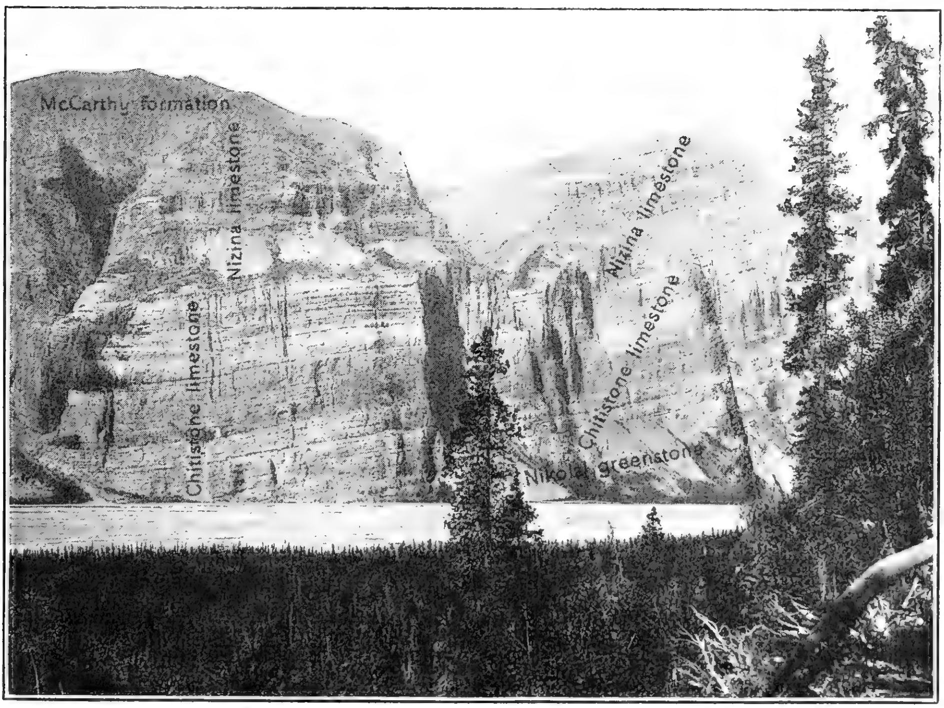

FIGURE 2.—McCARTHY FORMATION, NIZINA LIMESTONE, CHITISTONE LIMESTONE, AND NIKOLAI GREENSTONE ON WEST SIDE OF NIZINA RIVER, NEAR THE MOUTH OF CHITISTONE RIVER
Photograph by F. H. Moffit

UPPER TRIASSIC ROCKS, NIZINA VALLEY, ALASKA

	Feet
(Unconformity ?)	
Thin-bedded limestone, with some intercalated shale, probably including Nizina limestone. Contains *Orbiculoidea ?*, *Halobia* cf. *superba*, *Myophoria ?*, *Pecten*, *Tropites*, *Juvavites ?*, *Ceratites ?*, and *Arcestes ?*	500–3,000 ?
(Conformity.)	
Chitistone limestone (massive gray limestone, with *Terebratula*, *Spiriferina*, *Avicula*, *Halobia* cf. *superba*, *Gryphæa ?*, *Myophoria*, *Pecten*, *Hinnites ?*, *Pleuromya*, *Tropites ?*, and *Arcestes*)	300–1,200 ?
(Conformity ?)	
Triassic or Permian:	
Nikolai greenstone (basaltic lava flows)	6,500 ?
(Underlain conformity (?) by Carboniferous beds.)	

The basal formation of the undoubted Upper Triassic rocks of the Chitina Valley is the Chitistone limestone, which, as exposed in the type section in the Nizina Valley,[6] is a massive bluish gray limestone, 1,800 or 2,000 feet thick, which rests with apparent conformity (see plate 26, figure 1) on the volcanic beds of the Nikolai greenstone and which is overlain also with apparent conformity (see plate 26, figure 2) by the thin-bedded Nizina limestone which is described below.

On the tributaries of Kuskulana and Kotsina rivers, in the western part of the Chitina Valley, the Chitistone limestone seems to be reduced to a single massive plate which is, in general, not more than 300 to 500 feet thick. The Chitistone limestone thus has apparently thinned toward the west, while the overlying Nizina limestone has grown thicker. The exposures in the intervening district have not been studied in detail, so it is unfortunately not known whether there is a gradual change from the one section to the other. It is possible that the apparent westward thinning of the Chitistone limestone may be due to the cutting out of parts of the formation, in some places by faults and in other places by unconformity, and the apparent westward thickening of the overlying Nizina limestone may be caused by structural repetition of the beds (see plate 27, figure 2). If the apparent westward thinning of the Chitistone limestone actually exists as a purely stratigraphic feature, it may be due to variation in the volume of the original sediments, the limestone having been deposited in the form of a wedge-shaped plate thinning westward; or it may be due to variation in the character of the original sediments, the massive limestone beds of the eastern area grading westward into thin-bedded limestone and shale.

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[6] F. H. Moffit and S. R. Capps: Geology and mineral resources of the Nizina district, Alaska. U. S. Geol. Survey Bull., No. 448, 1911, pp. 21-28.

The fauna of the Chitistone limestone of the type area as now known consists wholly of marine invertebrates. The following list represents provisional identifications, by T. W. Stanton, of eighteen small collections from as many localities distributed throughout practically the whole thickness of the formation. This list does not adequately represent the entire fauna, for the collecting has been very far from exhaustive, and no attempt has been made to enumerate all the species, many of which are probably undescribed.

List of fossils from the Chitistone Limestone of the Nizina Valley

	Local occurrence
Corals	Talus from lower 1,000 or 1,500 feet.
Pentacrinus	Talus from lower 1,000 or 1,500 feet.
Terebratula	Near base and talus from lower 1,000 or 1,500 feet.
Spiriferina	Talus from lower 1,000 or 1,500 feet.
Avicula ?	Talus from lower 1,000 or 1,500 feet.
Pseudomonotis ?	Talus from lower 1,000 or 1.500 feet.
Halobia cf. *superba* Mojsisovics	Throughout.
Halobia	Near top and talus.
Myophoria ?	1,200 feet above base.
Hinnites ?	Talus from lower 1,000 or 1,500 feet.
Turbo ?	Near top.
Orthoceras	Near top.
Tropites	Near base.
Tropites ?	Talus.
Juvavites ? (2 or more species)	Near top and talus from lower 1,000 or 1,500 feet.
Arcestes	Near base and near top.
Arcestes ?	Throughout.
Atractites	Near top.

The Chitistone limestone of the western part of the Chitina Valley has yielded the following fossils. The exact position of most of these within the formation can not be stated with certainty on account of the complex structure:

List of fossils from the Chitistone Limestone of the Lakina, Kuskulana, and Kotsina Valleys

Corals ?	*Halobia ?*
Pentacrinus	*Gryphæa*
Terebratula	*Gryphæa ?*
Spiriferina	*Myophoria* (two or more species)
Avicula	*Pecten*
Halobia cf. *superba* Mojsisovics	*Pecten ?*

Hinnites ?	*Pseudomelania ?*
Hinnites ? cf. *Halobia occidentalis* Whiteaves	*Natica ?*
	Tropites ?
Pleuromya	*Arcestes*
Turbo ?	*Arcestes ?*

The Nizina limestone, here described under that name for the first time, includes the rocks described by Schrader and Spencer[7] as the unnamed lower member of the "Triassic series" or "Triassic shales and limestones." These rocks were described by Moffit and Capps[8] as the upper part of the Chitistone limestone, but all other descriptions of the Chitistone limestone have distinctly excluded these beds. The name "Nizina limestone" appears a few times[9] in Rohn's account of the geology of the Chitina Valley, being applied to the same beds that Rohn formally described as the Chitistone limestone. This use of "Nizina limestone" appears only incidentally in the descriptions of other formations and of the structure, and obviously was unintentional. The limestone to which it was applied has otherwise, without exception, been called the Chitistone limestone. For these reasons it is believed that this earlier use of the name can be ignored, and should not be regarded as invalidating its application to the formation here described.

The Nizina limestone consists of a succession of thin-bedded limestones with a minor amount of interstratified shale. Massive limestone beds occur rarely throughout the formation, and a few thick beds of shale may be seen. There is a more or less gradual progressive change in the character of the formation from the base toward the top, the number and thickness of the limestone beds decreasing upward. The lower part of the formation consists, at many places, of practically all limestone, broken only by very thin shaly partings. The greater part of the formation consists of a fairly regular alternation of limestone and shale beds in about the proportion of 5 or 10 parts of limestone to one of shale, the limestone beds being from 4 to 18 inches thick and the shale beds from 1 to 3 inches thick. Toward the top of the formation the proportion of shale increases still more, there being a more or less gradual transition into the shales and thin limestones of the overlying McCarthy formation. The thickness of the beds here described as the Nizina limestone was estimated by Schrader and Spencer as approximately 1,000 feet, and by Moffit and

[7] F. C. Schrader and A. C. Spencer: The geology and mineral resources of a portion of the Copper River district, Alaska. U. S. Geol. Survey, special publication, 1901, pp. 32, 33, 46-47.

[8] F. H. Moffit and S. R. Capps: Geology and mineral resources of the Nizina district, Alaska. U. S. Geol. Survey Bull., No. 448, 1911, pp. 21-27.

[9] Oscar Rohn: A reconnaissance of the Chitina River and the Skolai Mountains, Alaska. U. S. Geol. Survey, 20th Ann. Rept., pt. 2, 1900, pp. 427, 429, 431, 435.

Capps as about 1,200 feet. This latter estimate is approximately correct. The type section is in the cliffs on the west side of Nizina River, opposite the mouth of Chitistone River, and is shown in plate 26, figure 2. In this view the Chitistone limestone forms the lower vertical cliffs, which are about 2,000 feet high; the Nizina limestone forms the upper more sloping and uneven cliffs, which are partly covered by talus slopes; and the McCarthy formation forms the smooth slopes above the highest cliffs at the left. The Nizina limestone rests on the Chitistone limestone with apparent conformity and is overlain by the McCarthy formation. The latter contact also is apparently conformable in the type section, although there is evidence (see page 711) of an important unconformity at other localities. No fossils have as yet been obtained from the type section of the Nizina limestone.

In the Kuskulana and Kotsina valleys the Chitistone limestone is overlain by at least 1,000 or 2,000 feet (possibly several thousand feet) of thin-bedded limestones and shales.[10] These beds doubtless include the equivalent of the Nizina limestone and may include also the lateral equivalent of the upper part of the Chitistone limestone. The fauna of these beds appears to be essentially the same as that of the Chitistone limestone. This may indicate either that the fossiliferous thin-bedded limestones of the Kuskulana and Kotsina valleys are in part the lateral equivalent of the upper part of the Chitistone limestone, or that the fauna of the Chitistone limestone extends up into the overlying beds. The following list represents provisional identifications of 17 small collections of fossils from the supposed Nizina limestone of the Kuskulana and Kotsina valleys. The complex structure of this district (see plate 27) makes it impossible to identify the exact horizons represented by these collections, some of which may possibly have been obtained from thin fault blocks of the Chitistone limestone. The most striking difference between this fauna and that of the Chitistone limestone is in the presence of *Ceratites* (?), which was recognized in three collections. This is probably not a true *Ceratites,* for that genus is supposed to be characteristic of the Middle Triassic.

List of fossils from the thin-bedded (Nizina ?) limestone of Kuskulana and Kotsina Valleys

Orbiculoidea (?) sp.
Halobia cf. *superba* Mojsisovics.
Halobia sp.
Halobia (?) sp.
Myophoria (?) sp.
Pecten (two or three species).

[10] F. H. Moffit: The Kotsina-Kuskulana district, Alaska. U. S. Geol. Survey Bull., No. —. (In preparation.)

FIGURE 1.—THIN-BEDDED LIMESTONE AND SHALE AT FORKS OF ROCK CREEK

The apparent monoclinal dip is possibly close folding as in Figure 2. Photograph by F. H. Moffit

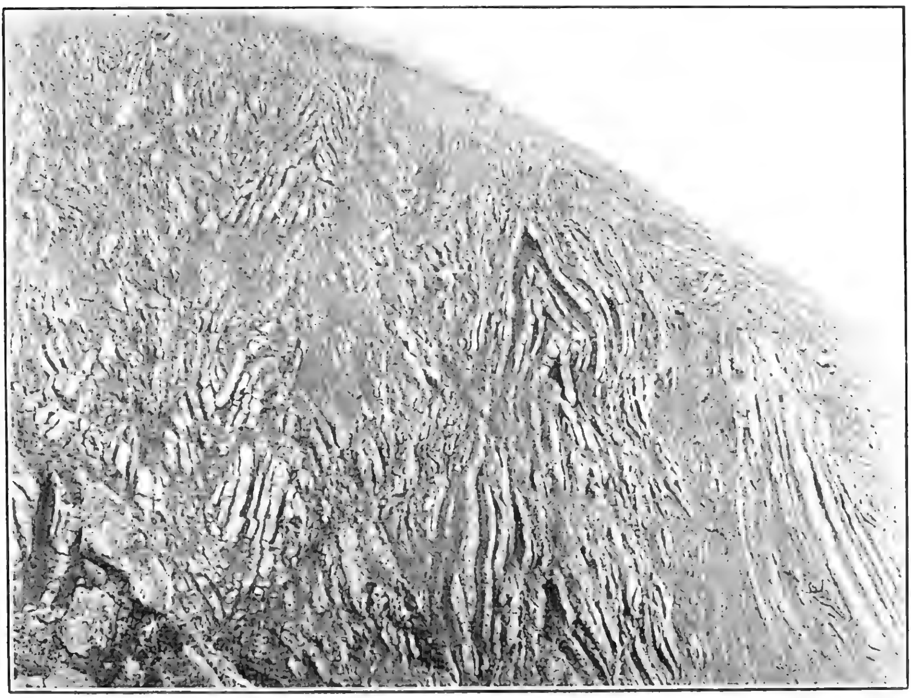

FIGURE 2.—THIN-BEDDED LIMESTONE AND SHALE ON WEST SIDE OF ROCK CREEK

Photograph by J. B. Mertie, Jr.

UPPER TRIASSIC ROCKS, KOTSINA VALLEY, ALASKA

Tropites sp.
Juvavites (?) sp.
Ceratites (?) sp.
Arcestes (?) sp.
Undetermined ammonites.

The uppermost division of the Upper Triassic rocks of the Chitina Valley is the McCarthy formation,[11] which directly overlies the thin-bedded limestones described above. The McCarthy formation consists of a conformable succession of shales, cherts, and limestones (see plate 28, figure 2), having an aggregate thickness of at least 1,500 feet and possibly of 2,500 feet or more. The section in the type district is as follows:

Section of part of McCarthy Formation on Nikolai Creek

	Feet
Black shale, with some chert beds (*Halobia* sp. and *Arniotites* (?) sp. near the top)	500
Thin-bedded black chert	800
Shales and thin-bedded shaly limestone	200

The uppermost beds of this section are exposed in a mountain top, but the neighboring mountains probably contain higher beds of the same formation. The top of the Upper Triassic sequence in this region has not been recognized.

There is apparently an unconformity at the base of the McCarthy formation, in the western part of the Chitina Valley, but it was not detected in the type section. The presence of an important unconformity in this position is also suggested by evidence from other districts (see page 711).

The chert beds in the lower part of the above section on Nikolai Creek are probably represented by a thick development of massive cherts in other parts of the Chitina Valley, notably on Fohlin and Fourth of July creeks. It is somewhat doubtful, however, as to whether the cherts of Fohlin and Fourth of July creeks should be regarded as a local facies of the basal member of the McCarthy formation, as a distinct formation occurring between the McCarthy formation and the underlying Nizina limestone, or as the local alteration product of limestone beds which possibly included both those of the McCarthy formation and of the thin-bedded Nizina limestone.

These cherts resemble, and apparently hold the approximate stratigraphic position of, the Upper Triassic cherts of the west coast of Cook Inlet and of the Kenai and Alaska peninsulas.

The fauna of the McCarthy formation consists chiefly of a single species, *Pseudomonotis subcircularis* (Gabb), which is characteristic of

[11] F. H. Moffit and S. R. Capps: Geology and mineral resources of the Nizina district, Alaska. U. S. Geol. Survey Bull., No. 448, 1911, pp. 28-30.

the highest known Triassic rocks of California and Nevada. This fossil is very closely related to, if not identical with, *Pseudomonotis ochotica* Keyserling, which is characteristic of the boreal facies of the Noric of Europe and Asia.

Nutzotin Mountains and Alaska Range.—A well defined, although probably discontinuous, belt of Triassic rocks extends through the southern foothills of the Nutzotin and Alaska Ranges from near the Canadian boundary to the headwaters of Susitna River. The eastern part of this belt, which is known as the Nabesna-White River district, lies north of the Chitina Valley and is separated from it by the Wrangell Mountains, in which the Quaternary and late Tertiary lavas and the existing glaciers conceal the underlying Mesozoic strata. Because of this lack of continuity and because of differences in the character of the sediments, the rocks in the two districts are somewhat difficult of correlation.

The Triassic rocks in the vicinity of Skolai Pass[12] include shales and overlying lavas, tuffs, breccias, etcetera. These rocks rest on a Permian ? (Artinskian) limestone. The shales are about 300 feet thick and contain interbedded tuffs in their upper part. The overlying pyroclastic rocks are of undetermined thickness. Both the shales and the overlying volcanic beds contain *Pseudomonotis subcircularis* (Gabb), and the latter have yielded also an undetermined species of *Clionites* (*Shastites*). The presence of *Pseudomonotis subcircularis* indicates that these rocks are to be assigned to the same general position as the McCarthy formation of the Chitina Valley, although that formation, as now known, does not contain volcanic material.

Limestones and shales of Upper Triassic age have been found in the vicinity of Cooper Pass,[13] which is in the southern foothills of the Nutzotin Mountains, about 50 miles northwest of Skolai Pass. The Triassic limestone occurs in close geographic and structural association with a massive Permian (?) limestone, but the stratigraphic relations to the Permian (?) limestone are not known. The fauna of the Triassic limestones and shales of Cooper Pass, as now known, includes only *Pseudomonotis subcircularis* (Gabb). The presence of this species, together with the similarity of the beds to the thin-bedded limestones and shales at the base of the McCarthy formation, suggests a correlation with rocks at that horizon.

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[12] C. W. Hayes: An expedition through the Yukon district. Nat. Geog. Mag., vol. 4, 1892, p. 140.

F. H. Moffit and Adolph Knopf: Mineral resources of the Nabesna-White River district, Alaska. U. S. Geol. Survey Bull., No. 417, 1910, p. 17.

[13] F. H. Moffit and Adolph Knopf: Mineral resources of the Nabesna-White River district, Alaska. U. S. Geol. Survey Bull., No. 417, 1910, pp. 27-32.

A belt of Triassic rocks extends through the foothills south of the Alaska Range from the headwaters of Gulkana River to a point west of Susitna River. This belt lies in a geographic and structural position similar to that of the Triassic rocks south of the Nutzotin Mountains, and should probably be regarded as their western discontinuous extension. The Triassic rocks south of the Alaska Range include[14] fossiliferous Upper Triassic limestone and a group of slates, tuffs, arkose, calcareous sandstones, and limestones that are closely associated with, and probably overlie, the fossiliferous limestone. The latter is underlain by basic lavas and tuffs that seem to rest on a Carboniferous (?) limestone, and that consequently correspond in stratigraphic position, as well as in lithologic character, to the Nikolai greenstone of the Chitina Valley, and should probably be assigned to the Permian or early Triassic.

The limestone, which occurs in a series of small detached areas, whose discontinuity is probably due to structural disturbances rather than to original lenticularity, is apparently only a few hundred feet thick, and contains *Halobia* cf. *superba* Mojsisovics, *Tropites* sp., *Discotropites (?)* sp., and *Arcestes* sp., which suggest a fauna closely similar to that of the Chitistone limestone.

The slate, tuff, arkose, and calcareous beds which apparently overlie the limestone just described have a thickness of many hundred, if not several thousand, feet. These beds contain *Pseudomonotis subcircularis* (Gabb), which, together with the position of the rocks relative to the underlying limestone, indicates that they belong in the same general position as the McCarthy formation. In lithologic character they correspond more closely to the Triassic volcanic beds of Skolai Pass and to the Triassic limestones and tuffs of Port Graham, both of which contain this same fossil.

Cook Inlet and southwestern Alaska.—The Triassic rocks of the west coast of Cook Inlet[15] include two fossiliferous Upper Triassic formations—the Kamishak chert and an older unnamed limestone. The local section also includes greenstones which are older than the fossiliferous Triassic rocks and which possibly belong in the Triassic. Beneath the greenstones are slates which the writer believes are probably Paleozoic, and above the Triassic rocks are porphyries and tuffs that are probably Lower Jurassic.

The Upper Triassic limestone of the west coast of Cook Inlet has been observed only at places of complex structure and generally in close asso-

[14] F. H. Moffit: Headwater regions of Gulkana and Susitna rivers, Alaska. U. S. Geol. Survey Bull., No. 498, 1912, pp. 22, 29-33.

[15] G. C. Martin and F. J. Katz: A geologic reconnaissance of the Iliamna region, Alaska. U. S. Geol. Survey Bull., No. 485, 1912, pp. 41-50.

ciation with the Kamishak chert. Its exact relations to the latter formation are somewhat doubtful, but it is believed to underlie it. It contains a species of *Halobia* which resembles the Alaskan species that is usually compared with *Halobia superba* Mojsisovics, and which may indicate that the limestone corresponds in general position with the Chitistone limestone and is of Karnic age.

The Kamishak chert consists of banded cherts, calcareous shales, and thin limestones in the upper part, grading downward into more massive beds of dark chert. The total thickness is at least 1,000 feet and probably exceeds 2,000 feet. The upper shaly and calcareous part of the formation contains *Pseudomonotis subcircularis* (Gabb), but the lower, more massive cherts have thus far yielded no fossils. The upper part of the formation is with little doubt the equivalent of at least part of the McCarthy formation and is of Upper Noric age. There is considerable doubt, however, concerning the exact age and correlation of the lower and more cherty members. There is a strong presumption in favor of correlating them with the cherts of Chitina Valley, which likewise are of somewhat doubtful age and position, although they apparently belong near the base of the McCarthy formation and are closely associated with, even though they may not include beds containing, *Pseudomonotis subcircularis* (Gabb).

The Triassic rocks of the east coast of Cook Inlet, which are situated in the southwest end of Kenai Peninsula, include[16] limestones and tuffs with Upper Triassic fossils. These beds are apparently underlain by contorted cherts which have yielded no characteristic fossils, but which the writer believes to be of Upper Triassic age. Beneath the cherts are ellipsoidal lavas which are underlain by slate and graywacke. The Upper Triassic limestones and tuffs are overlain, probably unconformably, by Lower Jurassic tuff and agglomerate.

The fossiliferous Upper Triassic rocks of the Kenai Peninsula, as exposed on Port Graham, are composed of limestones, cherts, and tuffs. Their thickness is at least 1,000 feet. *Pseudomonotis subcircularis* (Gabb) occurs near the top of the sequence, and lower down a species of *Halobia* has been found. The former species indicates that at least part of the succession is of Upper Noric age, and is to be correlated approximately with the McCarthy formation and with the banded cherts and calcareous shales in the upper part of the Kamishak chert. If the *Halobia* is identical with the Alaskan and California species usually referred to *Halobia superba* Mojsisovics, it possibly indicates that the lower

[16] G. C. Martin: The western part of Kenai Peninsula. U. S. Geol. Survey Bull., No. 587, 1915, pp. 52-63.

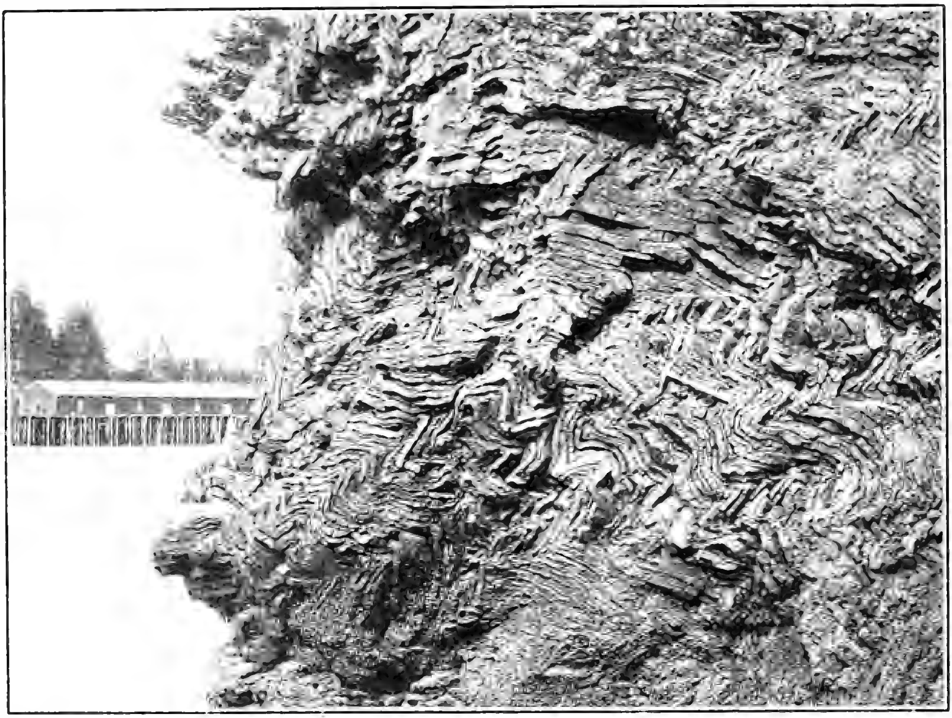

FIGURE 1.—CONTORTED CHERT, EAST SHORE SELDOVIA BAY, NEAR CANNERY. Photograph by U. S. Grant

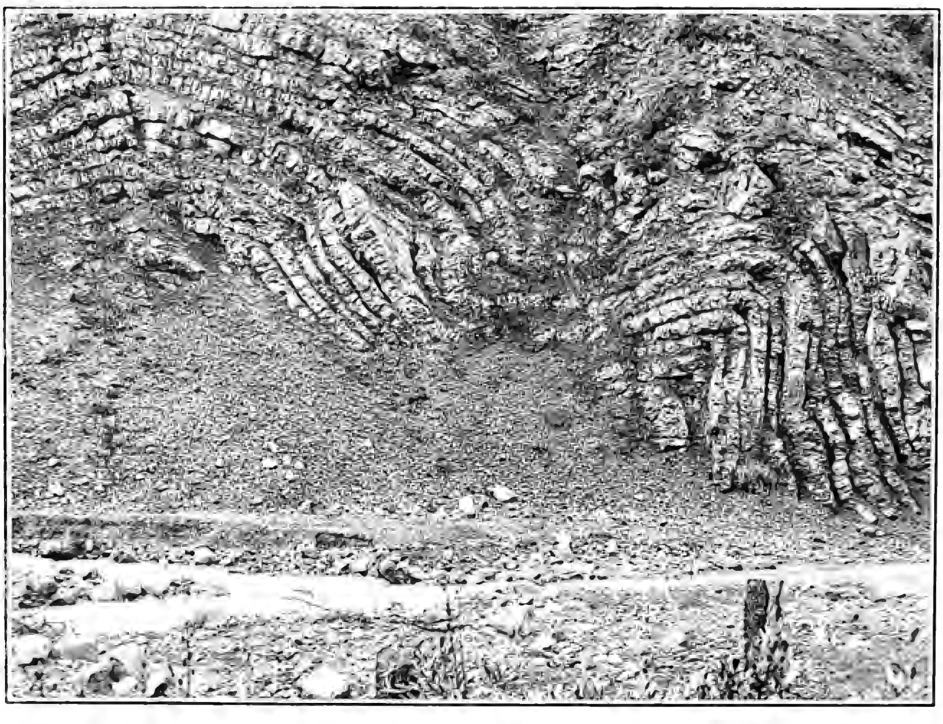

FIGURE 2.—PSEUDOMONOTIS-BEARING LIMESTONE AND SHALE IN LOWER PART OF McCARTHY FORMATION ON COPPER CREEK, NIZINA VALLEY. Photograph by F. H. Moffit

UPPER TRIASSIC ROCKS, COOK INLET AND NIZINA VALLEY, ALASKA

part of the sequence is of Karnic age and is to be correlated approximately with at least part of the Chitistone limestone of the Chitina Valley and of the Hosselkus limestone of California. The writer would suggest, however, that this *Halobia,* and possibly also the one that has been obtained from the west coast of Cook Inlet, may belong to the species which Stanton has noted[17] in the lower part of the Brock shale of California, or possibly to one of the species[18] that occur in the Lower Noric beds of Oregon. If this be the case, the occurrence of *Halobia* in these beds does not necessarily indicate that they are the equivalent of the Chitistone limestone or that they are older than the supposed Noric strata of California.

The contorted cherts of Kenai Peninsula (see plate 28, figure 1) have yielded no characteristic fossils and their age is somewhat doubtful. The local field relations indicate that the cherts lie immediately above the ellipsoidal lavas and beneath the limestones and tuffs, which seem to occur directly beneath the Lower Jurassic beds and to be the youngest Triassic rocks in the local section. This sequence accords well with the relations of similar beds in other regions, provided that the *Halobia* belongs to a species whose range is such that the limestones and tuffs can be correlated with the McCarthy formation and with the upper part of the Kamishak chert, and that the cherts can be correlated with the cherts at the base of the McCarthy and Kamishak formations. But if the *Halobia* is a strictly Karnic species which is restricted to the horizon of the Chitistone limestone and of the lower part of the Hosselkus limestone, the lower part of the limestones and tuffs must be correlated with rocks occurring beneath the cherts at the base of the McCarthy and Kamishak formations, and the cherts can not be considered as occurring beneath the limestones and tuffs of Port Graham and be correlated with any of the Triassic cherts known in other Alaskan districts. The writer believes that this *Halobia* is probably not an exclusively Karnic (lower Hosselkus) species, and that the cherts of Kenai Peninsula should be regarded as occurring beneath the limestones and tuffs and above the ellipsoidal lavas, and should be correlated with the cherts at the base of the McCarthy formation and with the lower part of the Kamishak chert.

The Upper Triassic rocks of the Alaska Peninsula[19] include limestone and shale, 700 feet or more in thickness, containing *Pseudomonotis sub-*

[17] T. W. Stanton, cited by J. S. Diller: Redding folio (No. 138), Geol. Atlas, U. S. Geol. Survey, 1906, p. 5.

[18] James Perrin Smith: The occurrence of coral reefs in the Triassic of North America. Am. Jour. Sci., 4th ser., vol. 33, 1912, p. 95.

[19] P. Fischer: Sur quelques fossiles de l'Alaska. Voyages à la côte nord-ouest de l'Amérique, pt. 1, 1875, pp. 33-36, pl. A.

T. W. Stanton and G. C. Martin: Mesozoic section on Cook Inlet and Alaska Peninsula. Bull. Geol. Soc. Am., vol. 16, 1905, pp. 393-396.

circularis (Gabb) (see plate 29, figure 1), underlain by contorted cherts in which no fossils have been obtained. The cherts are underlain by basic igneous rocks, while the Pseudomonotis-bearing beds are overlain by shales that may be either Triassic or Jurassic.

Similar contorted cherts, underlain by ellipsoidal lavas beneath which are slates and graywackes, occur near Uyak, on the northwest coast of Kodiak Island. No fossils have been obtained.

An Upper Triassic limestone occurring on Iliamna Lake[20] has yielded a fauna, composed chiefly of corals, which has not been recognized with certainty elsewhere in Alaska and which, according to Prof. J. P. Smith,[21] is of Lower Noric age. No other Triassic rocks are known at this locality.

Southeastern Alaska.—Upper Triassic rocks occur at several widely distributed localities in southeastern Alaska, where they consist chiefly of limestones having a thickness of apparently only a few hundred feet. A basal conglomerate has been recognized at several localities. The underlying rocks are Permian (?), except on Gravina Island, where they are Devonian. On Kupreanof Island the Triassic limestone is underlain by ellipsoidal lavas which bear a close resemblance to the lavas that underlie the Upper Triassic limestones at many other Alaskan localities. These lavas probably overlie a Permian (?) limestone. It is possible that much of the greenstone of southeastern Alaska belongs in this position.

The Triassic limestones of southeastern Alaska are in general characterized by faunas containing *Halobia* cf. *superba* Mojsisovics and consequently seem to correspond, at least approximately, in position to the Chitistone limestone, although these faunas contain elements not known in the fauna of the Chitistone limestone and which may indicate either a slightly different horizon or another facies of deposits of the same age. For example, the fossils from Hamilton Bay, Kupreanof Island, include species related to *Spiriferina borealis* Whiteaves and *Trachyceras (Dawsonites) canadense* Whiteaves, which are elsewhere known only in the Triassic rocks of Liard River, British Columbia, and of Bear Island, between Norway and Spitzbergen.

The Triassic rocks of Gravina Island,[22] which contain only a small proportion of limestone, consisting chiefly of conglomerate and shale, contain a fauna that, although including a species of *Halobia* resembling *Halobia superba* Mojsisovics, is of a somewhat different type from the other

[20] G. C. Martin and F. J. Katz: A geologic reconnaissance of the Iliamna region, Alaska. U. S. Geol. Survey Bull., No. 485, 1912, pp. 41-47.

[21] James Perrin Smith: The occurrence of coral reefs in the Triassic of North America. Am. Jour. Sci., 4th ser., vol. 33, 1912, pp. 92-96.

[22] P. S. Smith: Notes on the geology of Gravina Island, Alaska. U. S. Geol. Survey, Prof. Paper 95, 1915, pp. 100-104.

recognized Alaskan Triassic faunas. The abundant corals in some of the limestone beds on Gravina Island suggest that they may represent the Lower Noric coral fauna of Iliamna Lake.

It is only at Hamilton Bay,[23] on Kupreanof Island, that *Pseudomonotis subcircularis* (Gabb), indicative of the boreal Upper Noric, has been found. At this place the Pseudomonotis zone (the strata being overturned) is separated from the Halobia zone by a conglomerate which suggests an unconformity corresponding to the one for which the writer believes there is strong evidence at the base of the Pseudomonotis zone in the western part of the Chitina Valley and at Skolai Pass.

On Admiralty Island there are contorted cherts, somewhat similar to the Upper Triassic cherts of Cook Inlet, apparently overlying the Triassic limestone, but they have yielded no fossils and may not be Triassic.

The top of the Triassic beds of southeastern Alaska has not been recognized, but it is probably marked by a great unconformity, for the next younger sedimentary rocks known in this region are Lower Cretaceous or possibly Upper Jurassic.

Yukon River.—The only known Triassic rocks in the Yukon Valley are near the mouth of Nation River,[24] not far below the Canadian boundary. They consist of thin-bedded limestones and calcareous shales, at least 400 feet thick, resting probably with unconformity, though without marked discordance of bedding, on a lower Permian ? (Artinskian) limestone. The top of the Triassic rocks has not been observed, but since the next younger rocks known in this region are Lower Cretaceous, the upper contact of the Triassic rocks is probably marked by a profound unconformity.

Section of Upper Triassic strata on south bank of Yukon River, 1 *mile above Nation River*

	Feet
Calcareous shale and shaly limestone with *Pseudomonotis subcircularis* (Gabb), *Rhynchonella ?* sp., and *Terebratula* sp.	20+
Calcareous shale and shaly limestone with *Halobia* cf. *superba* Mojsisovics, *Pleurotomaria ?* sp., and *Clionites ?* sp.	320
Limestone with *Rhynchonella* sp., *Terebratula* sp., *Spiriferina* sp., *Halobia* sp., *Aviculipecten* sp., *Pecten* sp., *Pleurophorus ?* sp., *Natica ?* sp., *Orthoceras* sp., *Nautilus* sp., *Popanoceras* (*Parapopanoceras*) *?* sp., *Monophyllites ?* sp., *Placites ?* sp., and *Trachyceras* (*Protrachyceras*) *?* cf. *lecontei* Hyatt and Smith	60
(Underlain unconformably ? by lower Permian (?) limestone with an Artinskian fauna.)	

[23] W. W. Atwood: Some Triassic fossils from southeastern Alaska. Jour. Geology, vol. 20, 1912, pp. 653-655.

[24] Alfred H. Brooks and E. M. Kindle: Paleozoic and associated rocks on the upper Yukon, Alaska. Bull. Geol. Soc. Am., vol. 19, 1908, pp. 262, 297, 304-305, 313.

Three more or less distinct faunal zones are indicated by the fossils from the Triassic rocks near Nation River. The fauna of the lower limestone differs strikingly from any of the Triassic faunas recognized in the southern part of Alaska. Its Upper Triassic age is indicated by the ammonites, doubtfully identified as *Monophyllites, Placites,* and *Trachyceras (Protrachyceras) lecontei.* The ammonite doubtfully identified as *Popanoceras (Parapopanoceras)* sp. is suggestive of the Middle Triassic, but, since it is an immature specimen, its evidence is inconclusive and is overbalanced by that of the other fossils. The fauna differs strikingly from that of the Chitistone limestone and supposedly equivalent beds of the southern part of Alaska in the absence of such characteristic fossils as *Tropites, Juvavites, Arcestes,* and *Halobia* cf. *superba,* and in the abundance of the brachiopods and nautiloids. Its nearest relations among the known Alaskan faunas are with a fauna found on Canning River, with which it has several species in common, and possibly with some of the collections from Hamilton Bay on Kupreanof Island.

The calcareous shales and shaly limestones, with *Halobia* cf. *superba, Pleurotomaria* (?), and *Clionites* (?), which overlie the limestone just discussed and make up the greater part of the section exposed at this locality, are to be correlated approximately with the Chitistone limestone, although their fauna also differs from those of southern Alaska and resembles that of Canning River in the absence of the common ammonites of the southern region and in the probable presence of *Clionites.*

The beds at the top of the section, containing *Pseudomonotis subcircularis* (Gabb), represent the boreal Upper Noric horizon of the McCarthy formation.

Northeastern Alaska (Firth and Canning valleys).—The Upper Triassic rocks of northeastern Alaska are known in two districts—in the Firth Valley near the Canadian boundary, and in the vicinity of Canning River about 130 miles farther west. The Triassic rocks of these two districts are much alike, consisting mostly of limestone and shale. In both districts the underlying rocks are Permian (?) limestones, while probably in both places (certainly on Canning River) the overlying beds are Lower Jurassic shales.

The Upper Triassic rocks of Firth River[25] include black shales, thin-bedded shaly limestones, and possibly some massive limestone. They occur in two areas, in one of which the rocks contain *Halobia* cf. *superba* Mojsisovics, indicating a Karnic horizon, and in the other they contain

[25] A. G. Maddren: Geologic investigations along the Canada-Alaska boundary. U. S. Geol. Survey Bull., No. 520, 1912, pp. 300, 312-313.

Pseudomonotis subcircularis (Gabb), indicating the Upper Noric. The local relations of the rocks of these two areas are not known.

The Upper Triassic rocks of Canning River, according to the unpublished observations[26] of Mr. E. de K. Leffingwell, who has kindly permitted the use of the following statement, include limestones, shales, and sandstones aggregating about 500 feet in thickness. They are underlain by Permian (?) limestone and are overlain by Lower Jurassic beds.

The fauna of these rocks is certainly Upper Triassic, as is shown by the presence of *Clionites* and of *Halobia* cf. *superba* Mojsisovics. The presence of the latter fossil suggests a position in the middle or Karnic stage of the Upper Triassic, corresponding approximately to the horizon of the Chitistone limestone. The association of such genera as *Megalodon (?)* and *Aviculipecten,* which are not known from rocks younger than the Triassic, with such genera as *Gervillia, Gryphœa, Cardium, Natica,* and *Atractites,* which are not known from rocks older than the Triassic, would in itself indicate the Triassic age of this fauna. This fauna differs from the better known Triassic faunas of the southern part of Alaska in the entire absence of the corals and of such pelecypods as *Myophoria* and *Pleuromya,* and in the practical absence of the ammonites, especially in the absence of such ammonite genera as *Tropites, Juvavites,* and *Arcestes,* which are very abundant in most of the Triassic areas of southern Alaska. It differs also from the other known Alaskan Triassic faunas in the preponderance of the brachiopods and in the presence of *Gervillia* and *Megalodon (?),* and differs from most of the others in the presence of *Clionites.* The Alaskan fauna most closely related to this occurs in the lowest bed of the Triassic limestone near Nation River.

The presence of *Pseudomonotis subcircularis* (Gabb) in talus and float material at several localities in the Canning River district indicates the presence of beds corresponding to those of the McCarthy formation. The Pseudomonotis zone from which this material was derived may occur either in the uppermost part of this formation or in a thin overlying formation that has not been recognized.

Northwestern Alaska.—The known Triassic rocks of northwestern Alaska include cherts, shales, and thin-bedded limestones exposed in several areas near Cape Lisburne and in an area about 55 miles farther south, near Cape Thompson. The Triassic rocks of these two districts not only are practically identical in lithologic character, but apparently occur in very similar stratigraphic relations to the associated formations.

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[26] E. de K. Leffingwell: The Canning River region, northern Alaska. U. S. Geol. Survey, Professional Paper No. —. (In preparation.)

The Triassic rocks near Cape Thompson[27] consist of cherts, argillites, and thin-bedded limestones aggregating 625 feet in thickness. They rest with apparent conformity on unfossiliferous limestones which overlie a Mississippian (Lower Carboniferous) limestone and which are supposed to be of Carboniferous age. They are overlain with apparent conformity by shales that are possibly Jurassic or Cretaceous. *Pseudomonotis subcircularis* (Gabb) has been obtained near the top of the strata referred to the Triassic.

The Triassic rocks near Cape Lisburne[28] consist of thinly bedded black slates, shales, cherts, and cherty limestones, having a thickness of over 1,000 feet and containing *Pseudomonotis subcircularis* (Gabb). They constitute the "Middle formation" of the Carboniferous as described by Collier. Neither base nor top of these beds has been recognized, all the observed contacts being faults. The next older rocks known in the vicinity are the Carboniferous ("Mississippian") beds of the Lisburne limestone, and the next younger are the Middle or Upper Jurassic beds of the Corwin formation.

The southeastward extension of the Pseudomonotis-bearing beds of Capes Lisburne and Thompson is indicated by the presence of cherty limestone float containing *Pseudomonotis subcircularis* (Gabb) in the Noatak Valley.[29]

Pseudomonotis subcircularis has been found also in float material on Saint Lawrence Island. This does not, however, prove that Triassic beds outcrop on the island, for the fossiliferous boulders may have been transported by ice from the mainland, possibly from the outcrops on the shore near Cape Lisburne.

General Character and Correlation

MIDDLE TRIASSIC

The only known Middle Triassic rocks in Alaska are the slates of Brooks Mountain, Seward Peninsula. It has already been shown that these rocks occur in a region where no other Triassic rocks are known, and that Middle Triassic rocks that can be correlated with them do not occur in other Alaskan regions.

The fossils from this locality include a species of *Daonella* (see plate 30, figure 3) that is closely related to, although probably not identical with,

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[27] E. M. Kindle: The section at Cape Thompson, Alaska. Am. Jour. Sci., 4th ser., vol. 28, 1909, pp. 521-522, 526-528.

[28] A. J. Collier: Geology and coal resources of the Cape Lisburne region, Alaska. U. S. Geol. Survey Bull., No. 287, pp. 16, 18, 19-21, pl. 1.

[29] P. S. Smith: The Noatak-Kobuk region, Alaska. U. S. Geol. Survey Bull., No. 536, 1913, pp. 79-80.

		Alaskan equivalents.	Queen Charlotte Islan	Pine River.
Upper Triassic.	Upper Noric.	McCarthy formation and equivalent beds with Pseudomonotis subcircularis.	Flaggy calcareous arg and thin limestones Pseudomonotis subc laris.	f unknown ch Pseudomonot laris.
	Lower Noric.	Limestone of Iliamna Lake with corals. ? Nizina limestone (in part ?).	(Unconformity.)	
	Middle and Upper Karnic.	Chitistone and Nizina (?) limestones and equivalent beds with Halobia cf. superba.	Massive limestone.	
	Lower (?) Karnic.	Dawsonites-bearing beds of Hamilton Bay.		
Middle Triassic.		Slates of Brooks Mountain, Seward Peninsula, with Gymnotoceras and Daonella.		
Permian (?) or Triassic.		Nikolai greenstone and equivalent volcanic rocks.	Volcanic rocks.	

the species from Nevada and California which has been referred to *Daonella lommeli* Wissman, and an undetermined species of *Ceratites (Gymnotoceras)*. *Daonella lommeli* Wissman is a European species which is considered as characteristic of beds that are generally referred to the Ladinic, and, according to most writers, are regarded as representing the uppermost division of the Muschelkalk, or Middle Triassic, although they are sometimes regarded as constituting the lowest division of the Upper Triassic. The fossils from Nevada that have sometimes been considered as identical with *Daonella lommeli* are regarded[30] by Prof. James Perrin Smith as constituting a distinct species, *Daonella dubia* Gabb, and as belonging near the middle of the Middle Triassic. *Gymnotoceras* is an ammonite which is supposed to be highly characteristic of the Arctic type of Middle Triassic faunas. All known American species of *Gymnotoceras* are characteristic of the *Daonella dubia* zone of the Middle Triassic of Nevada. The Alaskan fossils are presumably to be regarded as belonging in approximately the same position.

The same horizon is probably represented by part of the Nicola series of the Interior Plateau region of British Columbia (see figure 1). The Nicola series[31] is a thick succession of volcanic rocks with some interbedded limestones and argillites containing[32] *Pentacrinus asteriscus (?), Terebratula humboldtensis, Spiriferina* or *Cyrtina*, *Myacites* cf. *humboldtensis, Daonella* cf. *lommeli, Trigonodus, Cardita,* and *Panopea* cf. *remondi*. The Nicola series has been supposed to contain *Pseudomonotis subcircularis,* but this fossil does not occur in association with the others, having been obtained[33] from an outlying area of argillites resting on volcanic beds that were correlated with those of the Nicola series.

It should be noted that *Daonella lommeli* has been reported from many other localities in British Columbia. Since in most of these cases more or less doubt has been expressed concerning the identification; since the Canadian fossil doubtfully referred to this species has never been described or figured; and since in nearly all cases the fossil has been listed as occurring in close association with characteristic Upper Triassic forms, the writer believes that the species may have been incorrectly identified, and that it probably is Upper Triassic species of *Halobia*. There is as yet

[30] James Perrin Smith: The Middle Triassic marine invertebrate faunas of North America. U. S. Geol. Survey, Prof. Paper 83, 1914, pp. 143-144.

[31] George M. Dawson: Report on the area of the Kamloops map-sheet, British Columbia. Geol. Survey of Canada, Ann. Rept. (new series), vol. vii, 1896, pp. 49B-62B, 112B-146B.

[32] Idem., pp. 50B-51B (The crinoid and brachiopods were identified by Whiteaves, the pelecypods by Hyatt.)

[33] George M. Dawson: Preliminary report on the physical and geological features of the southern portion of the interior of British Columbia. Geol. Survey of Canada. Report of progress for 1877-1878, pp. 66B-67B.

Correlation of the Triassic Rocks of British Columbia and Yukon

		Alaskan equivalents.	Queen Charlotte Islands.	Vancouver Island, north end.	Islands east of Vancouver Island.	Vancouver Island, southern part.	Forty-ninth parallel.	Whipsaw Creek.	Kamloops district.	Stikine River.	Pine River.	Peace River.	Liard River.	Stewart River.
Upper Triassic.	Upper Noric.	McCarthy formation and equivalent beds with Pseudomonotis subcircularis.	Flaggy calcareous argillite and thin limestones with Pseudomonotis subcircularis.	Flaggy limestone and argillites.	Parson Bay group (shale, argillite, and impure limestone with Pseudomonotis subcircularis and Arniotites vancouverensis).		Cultus formation (argillites with Arniotites vancouverensis? and Aulacoceras? cf. carlottensis).	Argillites with Pseudomonotis subcircularis.		? Shaly rocks near Glenora with Halobia.	Beds of unknown character with Pseudomonotis subcircularis.	Impure limestones and shales with Pseudomonotis subcircularis.		Impure limestone, argillites, and quartzites (with Pseudomonotis subcircularis and Halobia).
	Lower Noric.	Limestone of Iliamna Lake with corals. ? Nizina limestone (in part?).	(Unconformity.)			? Sutton formation (limestone with Choristoceras, Myophoria, and corals).								
	Middle and Upper Karnic.	Chitistone and Nizina (?) limestones and equivalent beds with Halobia cf. superba.	Massive limestone.	Massive limestone.										
	Lower (?) Karnic.	Dawsonites-bearing beds of Hamilton Bay.											Calcareous shales, sandstones, and limestones with Dawsonites canadense, Nathorstites McConnelli, etc.	
Middle Triassic.		Slates of Brooks Mountain, Seward Peninsula, with Gymnotoceras and Daonella.							Nicola series (volcanic rocks and interbedded limestone and argillite with Daonella cf. lommeli, etc.).					
Permian (?) or Triassic.		Nikolai greenstone and equivalent volcanic rocks.	Volcanic rocks.	Volcanic rocks.	Valdes group (lavas and tuffs).									

no proof that Middle Triassic rocks are present in British Columbia, except in the Kamloops district (see page 714).

UPPER TRIASSIC

General distribution.—Upper Triassic rocks are widely distributed throughout those parts of Alaska occupied by the Pacific, Rocky, and Arctic Mountain systems, which are the three major mountain regions of that territory. The Triassic deposits in each of these regions constitute a section which, in its general stratigraphic and faunal character, is more or less typical of that entire region, but which differs in greater or less degree from the sections in the other regions. These resemblances and differences possibly mean that the present major mountain areas occupy the sites of Triassic basins of deposition. The most complete local representation of these rocks is in the Chitina Valley, which must now, and probably will always, be regarded as containing the typical and standard section of the Upper Triassic rocks of Alaska, and more especially of the Pacific Mountain region. The Chitina Valley section is typical in all its more essential features, both stratigraphic and faunal, of the Upper Triassic deposits of southern Alaska, although several horizons known in other Alaskan districts have not yet been recognized here. The Upper Triassic rocks of the region south of the Alaska Range are underlain in most places by volcanic beds that include the Nikolai greenstone of the Chitina Valley and the similar, and probably corresponding lavas, or tuffs and lavas of other districts. Volcanic rocks are not present in this stratigraphic position north of the Alaska Range, where the Upper Triassic rocks rest directly on late Paleozoic limestones.

Dawsonites zone.—The occurrence in southeastern Alaska of an Upper Triassic limestone that is probably older than any Upper Triassic beds known elsewhere in Alaska is indicated by the presence, on the shores of Hamilton Bay, Kupreanof Island, of float containing fossils related to *Spiriferina borealis* Whiteaves and *Dawsonites canadense* Whiteaves. Neither of these species have been found elsewhere in Alaska or at any American localities except in the Triassic rocks of Liard River, in the eastern foothills of the Rocky Mountains of British Columbia.

The Triassic rocks of Liard River (see figure 1), according to McConnell,[34] "consist of dark shales, usually rather coarsely laminated, and passing into calcareous shales interstratified with sandstones and shaly and massive limestones." The fossils, which have been described by Whit-

[34] R. G. McConnell: Report on an exploration in the Yukon and Mackenzie basins, Northwest Territory. Annual Report of the Geological and Natural History Survey of Canada, new series, vol. iv, 1890, pp. 19D, 49D.

eaves,[35] include eleven species, among which are *Spiriferina borealis* Whiteaves and *Dawsonites canadense* Whiteaves, which have been doubtfully identified from Hamilton Bay. Mojsisovics[36] has pointed out that some of these fossils are indicative of Karnic age. Three of the Liard River species (*Dawsonites canadense, Nathorstites McConnelli,* and *Nathorstites lenticularis*), one of which occurs at Hamilton Bay, have been found, according to Böhm,[37] in the Upper Triassic rocks of Bear Island between Norway and Spitzbergen. The Triassic rocks of Bear Island are generally regarded as of Karnic (possibly Lower Karnic) age, and an assignment of the beds on Liard River to the same position has been made by Frech[38] on the basis of the presence of the above mentioned species, which are common to the two regions.

The Hamilton Bay fauna may also be tentatively correlated with that from Bear Island and referred to the Karnic. This fauna possibly represents a boreal facies of the Karnic which has not been recognized farther south in North America.

Zone of Halobia cf. *superba*.—The Chitistone limestone, which is the basal formation of the Upper Triassic section in Chitina Valley, is represented in other parts of the Pacific Mountain system by limestones which, although thinner, are similar to the Chitistone limestone in their general lithologic character, in their stratigraphic position between underlying volcanic rocks and overlying shales or cherts with *Pseudomonotis,* and in the general character of their fauna. The limestones which should be correlated with the Chitistone limestone include those of the upper Susitna Valley, of Herring Bay on Admiralty Island, and part of the Triassic limestone of Hamilton Bay on Kupreanof Island.

The fauna of these limestones includes unidentified species of *Tropites, Juvavites (?),* and *Arcestes,* a species of *Halobia* closely related to *Halobia superba* Mojsisovics, and many other fossils of lesser significance. These fossils show that the fauna is certainly Upper Triassic, and that it probably belongs in the middle or Karnic stage of the Upper Triassic. Although most of the identified genera of brachiopods and pelecypods have a long range, yet both the character of many of the individual forms and the general aspect of the assemblage are unmistakably Triassic. The

[35] J. F. Whiteaves: On some fossils from the Triassic rocks of British Columbia. Contributions to Canadian paleontology, vol. 1, pt. ii, No. 3, 1889, pp. 127-149, pls. 17, 18.

[36] Edmund von Mojsisovics: Beiträge zur Kenntniss der obertriadischen Cephalopoden-Faunen des Himalaya. Denkschriften der kaiserlichen Akademie der Wissenschaften. Wien, Bd. lxiii, 1896, p. 697.

[37] Johannes Böhm: Ueber die obertriadische Fauna der Bäreninsel. Kungliga Svenska Vetenskaps-Akademiens Handlingar. Bandet 37, No. 3, 1903, pp. 56-58, 61-64, 73-76.

[38] Fritz Frech: Die zirkumpacifische Trias. Lethæa geognostica, Teil ii, Das Mesozoicum, Band 1, Trias, 1908, pp. 488-491, 508.

ammonites all belong to highly characteristic Upper Triassic genera and point strongly toward a horizon in the Karnic, as does also the pelecypod identified as *Halobia* cf. *superba* Mojsisovics. The latter, according to Stanton, is identical with the species known by that name in the Triassic rocks of California, and is very closely related to, even though it may not be the same as, *Halobia superba* of the Triassic rocks of Europe. The Chitistone limestone may be regarded as certainly the equivalent of at least part of the Hosselkus limestone of California, and as probably representing in general the lower part of the Hosselkus limestone. The Chitistone fauna belongs to the Mediterranean type of Triassic faunas and is believed to be indicative of warm-water conditions.

On the Yukon River and in the eastern part of the Arctic Mountains (Firth and Canning valleys) are limestones which seem to correspond in general position to the Chitistone limestone. The fauna of these limestones is connected with that of the Chitistone limestone by the presence of *Halobia* cf. *superba* (see plate 29, figure 2), although it differs from it in the absence of the characteristic ammonite genera *Tropites, Juvavites,* and *Arcestes,* of the corals, and of such pelecypods as *Myophoria* and *Pleuromya.* It differs also in the abundance of the brachiopods and in the presence of *Clionites* and several other genera that have not been found in the Chitistone limestone. This fauna may represent the boreal facies of the Karnic, which is elsewhere not well developed in America. The writer regards these beds as probably being approximately synchronous with the Chitistone limestone, but as having been deposited in a different basin.

It is highly probable that the equivalent of the Chitistone limestone is present in the Queen Charlotte Islands, British Columbia (see figure 1), where Dawson has described[39] a massive limestone at least 400 feet thick resting on volcanic rocks and overlain by thin-bedded limestones and flaggy calcareous argillites containing *Pseudomonotis subcircularis.* The similarity of this section to that of the Chitina Valley is striking and suggestive. It is not possible, however, to establish this correlation definitely on paleontologic evidence, for the published lists[40] of fossils unfortunately do not indicate which of the species described by Whiteaves[41] were obtained from the massive limestone. A suggestion that these fossils

[39] George M. Dawson: Report on the Queen Charlotte Islands. Geol. Survey of Canada. Report of progress for 1878-1879, pp. 48B, 55B, 61B-62B, 63B.

[40] Idem., pp. 49B, 53B.

[41] J. F. Whiteaves: On some fossils from the Triassic rocks of British Columbia. Contributions to Canadian paleontology, vol. 1, pt. ii, No. 3, 1889, pp. 133-134, 141-142, 148-149.

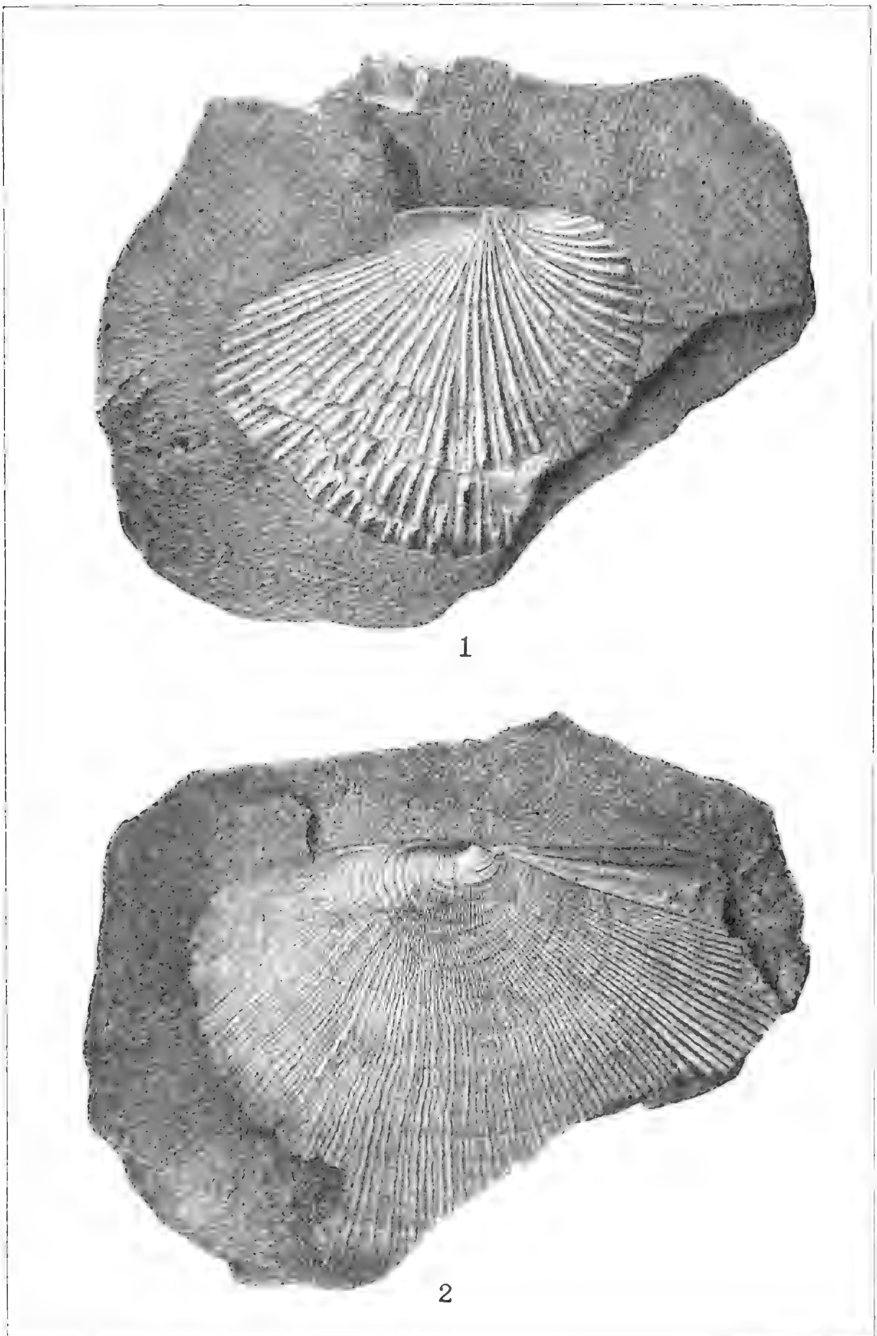

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FIGURE 1.—PSEUDOMONOTIS SUBCIRCULARIS (GABB)

Right valve from Upper Triassic limestone and shale of Cold Bay, Alaska Peninsula (3107)

FIGURE 2.—HALOBIA SP. CF. HALOBIA SUPERBA MOJSISOVICS

From Upper Triassic shaly limestone about 100 feet above base of section on page 701. South bank of Yukon River, one mile above Nation River (8897)

TRIASSIC FOSSILS FROM ALASKA

include Karnic forms has been made by Mojsisovics,[42] who said: "The same conclusion [of Karnic age] holds for *Aulacoceras carlottense,* since the genus *Aulacoceras* until now has been known only in the Karnic. The fragment of a coil figured as *Acrochordioceras (?) carlottense* may belong to a *Juvavites.*"

The same horizon is possibly present at the north end of Vancouver Island, where, according to Dawson,[43] the section is very similar to that in the Queen Charlotte Islands, and includes a massive limestone, possibly 1,000 feet thick, underlain by volcanic rocks and overlain by "flaggy limestones interbedded with calcareous argillites, black flinty argillites, and felsites." This limestone, and also the supposedly equivalent limestone of the Queen Charlotte Islands, is part of the thick and heterogeneous aggregate of rocks that has been described as the Vancouver series.

Coral-reef horizon.—An Upper Triassic limestone, occurring on Iliamna Lake, has yielded a fauna, composed chiefly of corals, which has not been recognized with certainty elsewhere in Alaska and which, according to Prof. James Perrin Smith, is of Lower Noric age and is to be correlated[44] with the coral-reef zone in the upper part of the Hosselkus limestone of California and in the Blue Mountains of Oregon and with the Zlambach fauna of the Alps. The position of this limestone in the Chitina Valley section is above the Halobia zone of the Chitistone limestone and below the Pseudomonotis zone of the McCarthy formation. It may be represented by the thin-bedded Nizina limestone or by beds that have been cut out by an unconformity at the base of the McCarthy formation.

This limestone may be present also on the west coast of Cook Inlet and on Gravina Island, in southeastern Alaska, but at neither of these localities has it been recognized with certainty.

The Lower Noric coral-reef horizon is possibly represented in British Columbia (see figure 1) by the Sutton limestone[45] of Cowichan Lake, Vancouver Island. The fauna of the Sutton limestone has been described by Clapp and Shimer,[46] who referred it to the lower part of the Lower Jurassic on the ground that its species are more primitive than certain

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[42] Edmund von Mojsisovics: Beiträge zur Kenntniss der obertriadischen Cephalopoden-Faunen des Himalaya. Denkschriften der kaiserlichen Akademie der Wissenschaften. Wein, Bd. lxiii, 1896, p. 697.

[43] George M. Dawson: Report on a geological examination of the northern part of Vancouver Island and adjacent coasts. Geological and Natural History Survey of Canada, vol. ii, new series, 1886, pp. 9B, 60B, 76B, 89B, 91B.

[44] James Perrin Smith: The occurrence of coral reefs in the Triassic of North America. Am. Jour. Sci., vol. 33 (4th series), 1912, pp. 92-96.

[45] Charles H. Clapp: Southern Vancouver Island. Geol. Survey of Canada, Memoir No. 13 (1121), 1912, pp. 36, 61-69.

[46] C. H. Clapp and H. W. Shimer: The Sutton Jurassic of the Vancouver group, Vancouver Island. Proc. Boston Soc. Nat. Hist., vol. 34, No. 12, 1911, pp. 425-438, pls. 40-42.

species from the Middle and Upper Jurassic of England and India, and are less primitive than certain species from the Rhætic of Europe, and that it does not contain *Daonella lommeli, Halobia superba,* or *Pseudomonotis subcircularis.* They regarded it as representing a Eurasian type of Liassic fauna which is rather closely related to certain unspecified Liassic faunas of Europe and India.

The writer believes that the reasons stated for the reference of this fauna to the Lower Jurassic are, to say the least, by no means conclusive. The absence of *Daonella lommeli, Halobia superba,* and *Pseudomonotis subcircularis* does not make its assignment to the Triassic impossible or even improbable. On the other hand, the fact that all of the five recognized genera occur abundantly in the Triassic, while two of them (*Choristoceras* and *Myophoria*) are highly characteristic of the Triassic, being authentically known, as far as the writer is aware, only in rocks of that system, makes it appear highly probable that this fauna is of Triassic age. The superficial resemblance of the corals, moreover, to those of the Lower Noric reefs of California, Oregon, Alaska, and the Alps suggests that the Sutton fauna may also be of Lower Noric age. In this connection it should be pointed out that the only recognized ammonoid genus, *Choristoceras,* in the Sutton fauna occurs also in association with the Zlambach corals of the Alps.

Chert horizon.—The cherts that form the lower part of the McCarthy formation of the Chitina Valley are apparently the equivalent of the more massive lower part of the Kamishak chert of the west coast of Cook Inlet and of the cherts that occur in a corresponding stratigraphic position beneath the Pseudomonotis zone of the Alaska Peninsula. The contorted cherts of Kenai Peninsula, of Kodiak Island, and of Herring Bay on Admiralty Island are probably also to be assigned to the same position, though on more slender evidence. The occurrence of these cherts below the Pseudomonotis zone and above the Halobia zone in the Chitina Valley indicates their general position, but since they contain no fossils they can not be assigned to a definite horizon or be correlated with any rocks of other regions.

Zone of Pseudomonotis subcircularis.—The highest Upper Triassic rocks known in Alaska are the Upper Noric Pseudomonotis-bearing beds, which are widely distributed throughout the three major mountain regions. This horizon is represented in the Pacific Mountain belt by the McCarthy formation of the Chitina Valley and by strata carrying a similar fauna at the head of White River, at Cooper Pass, in the Upper Susitna Valley, on both shores of Cook Inlet, on the Alaska Peninsula, and on Kupreanof Island in southeastern Alaska. In the Rocky Mountain

area Pseudomonotis-bearing beds form the upper part of the Triassic section near Nation River. Rocks belonging at the same horizon occur at many places throughout the Arctic Mountains, being known on Firth, Canning, and Noatak rivers and at Cape Lisburne and Cape Thompson.

These rocks consist, in general, of shales and flaggy limestones. They contain chert beds in the Chitina Valley, on both shores of Cook Inlet, at Cape Lisburne, at Cape Thompson, and in the Noatak Valley. Volcanic material is present at the head of White River, in the Upper Susitna Valley, and on Kenai Peninsula.

The writer believes that there is an important unconformity at the base of the Pseudomonotis-bearing beds of Alaska and British Columbia. The evidence for this unconformity is as follows:

In the western part of the Chitina Valley, notably in the valley of Elliot Creek and in the hills between Rock and Copper creeks, shales having the lithologic and faunal character of those of the McCarthy formation occur not far above the top of the Chitistone limestone, thus apparently occupying the normal stratigraphic position of the Nizina limestone, over 1,000 feet thick, which elsewhere separates these two formations. In the vicinity of Skolai Pass, near the head of White River, the Pseudomonotis zone immediately overlies a Permian (?) limestone. There is consequently an hiatus represented in the Nizina Valley, about 20 miles distant, by the Nikolai greenstone, the Chitistone limestone, and the Nizina limestone, which have an aggregate thickness of at least 7,000 or 8,000 feet. At Hamilton Bay, Kupreanof Island, in southeastern Alaska, the Pseudomonotis zone is separated from the older Halobia zone (the strata being inverted) by a conglomerate containing fossiliferous boulders of the older limestone. It is evident that the same unconformity is present on Cumshewa Inlet, Queen Charlotte Islands, where Dawson has described[47] the relations as follows:

> "On the southeast side of the South Arm flaggy argillites occur. They were observed to become conglomeratic in one place with fragments of the underlying [Triassic] limestone, which might be supposed to show that they belong to the coal-bearing [Cretaceous] series. They hold, however, the characteristic Triassic *Monotis*."

Further evidence of an unconformity at the base of the Pseudomonotis zone is indicated by the apparent absence at most places of the coral-bearing strata that belong below the Pseudomonotis zone and above the Halobia zone. The fact that in both Alaska and in British Columbia the

[47] George M. Dawson: Report on the Queen Charlotte Islands. Geol. Survey of Canada. Report of progress for 1878-1879, p. 82B.

Pseudomonotis-bearing beds have a far wider distribution than the older Halobia-bearing beds, and that the intervening coral-reef limestone is even more restricted, occurring only near the present continental margin, also suggests an Upper Noric transgression following a Lower Noric recession of the sea. The abrupt change in faunal character from the supposedly warm-water Halobia zone to the boreal Pseudomonotis zone also

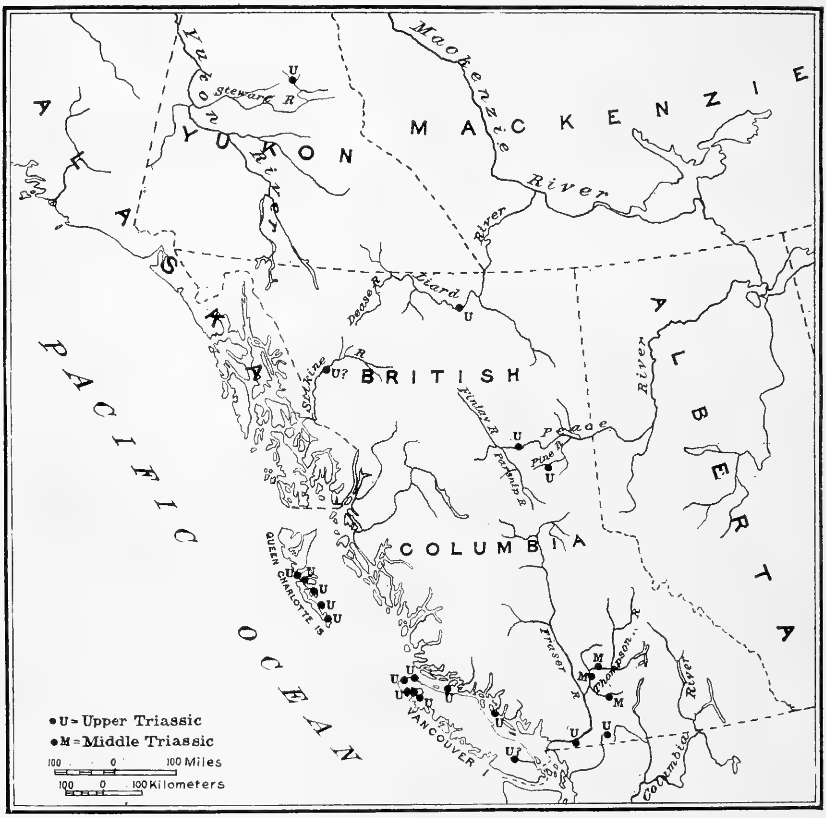

FIGURE 1.—*Map of British Columbia and Yukon, showing known Triassic localities*

suggests a withdrawal of the Karnic sea, followed by an Upper Noric transgression, presumably from the Arctic regions.

The fauna of the McCarthy formation as now known includes *Pseudomonotis subcircularis* (Gabb), *Halobia* sp., *Pecten* sp., and *Arniotites (?)* sp. The Pseudomonotis-bearing beds of the other Alaskan districts are correlated with the McCarthy formation on the basis of general lithologic similarity and sequence and also on the basis of the presence of *Pseudo-*

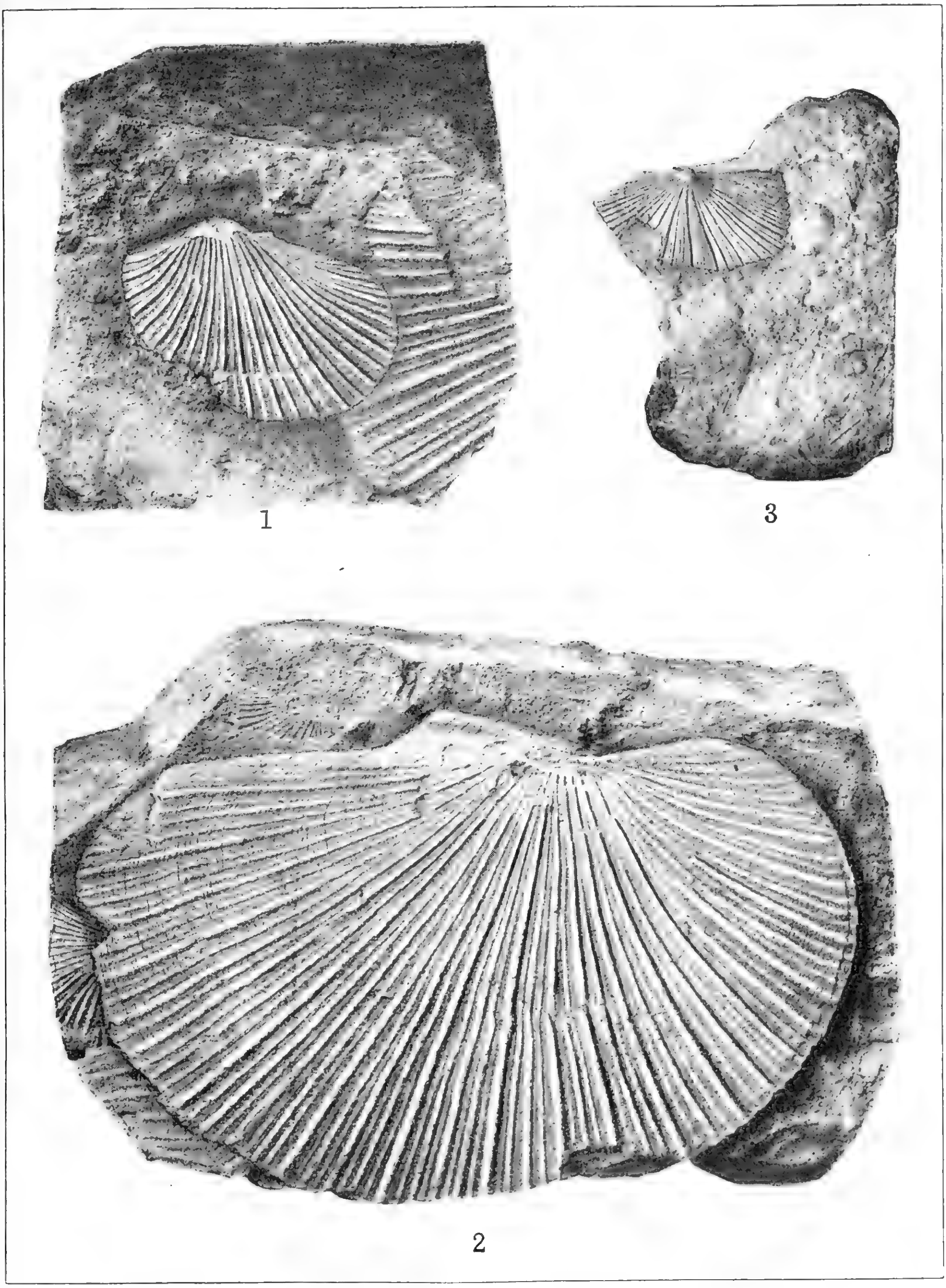

FIGURE 1.—SMALL LEFT VALVE OF PSEUDOMONOTIS SUBCIRCULARIS (GABB)
From Brock shale, one mile south of Mewittapom Mountain, Redding quadrangle, California

FIGURE 2.—LARGE RIGHT VALVE OF PSEUDOMONOTIS SUBCIRCULARIS (GABB)
From Brock shale, one mile south of Mewittapom Mountain, Redding quadrangle, California

FIGURE 3.—DAONELLA SP. CF. DAONELLA LOMMELI WISSMAN
From Middle Triassic slates on southeast slope of Brooks Mountain, Seward Peninsula, Alaska (5654)

TRIASSIC FOSSILS FROM ALASKA AND CALIFORNIA

monotis subcircularis (see page 29, figure 1). This is the only fossil recognized in these beds at most localities, although a few fossils have been found associated with the *Pseudomonotis* at some places. These include *Clionites (Shastites)* sp. at the head of White River, *Arca (?)* sp. on the west coast of Cook Inlet, *Rhynchonella (?)* sp. and *Terebratula* sp. near the mouth of Nation River, and some undetermined pelecypods near Cape Lisburne.

The presence of *Pseudomonotis subcircularis* in these beds is sufficient evidence for their approximate correlation with the Brock shale of Shasta County, California, with the Swearinger slate of Plumas County, California, and with the Pseudomonotis-bearing slates and slaty limestones of the West Humboldt Range, Nevada.

In British Columbia and Yukon there is an extensive development of Pseudomonotis-bearing beds that can be correlated on the basis of faunal content, as well as of stratigraphic sequence, with those of Alaska. They occur (see figure 1) in two well defined belts—a western or coastal belt that includes Triassic areas in the Queen Charlotte Islands, on Vancouver and the adjacent islands, and at the northern end of the Cascade Range; and an eastern or interior belt that is situated on the eastern front of the Rocky Mountains, and that includes known Triassic areas on Pine, Peace, and Stewart rivers.

The Pseudomonotis-bearing beds of Queen Charlotte Islands, according to Dawson,[48] consist of flaggy calcareous argillites and thin limestones more than 1,000 feet thick. These beds are underlain by massive limestone and are overlain[49] by feldspathic sandstone, coarse conglomerate, and agglomeratic rocks that Dawson considered Cretaceous, but which are now known to be Lower and Middle Jurassic.[50] These rocks have all been included in the Vancouver series. The contact of the argillites with the underlying limestone, although supposed to be in general conformable, is apparently unconformable, in at least one locality, according to Dawson's description.[51] The fossils listed from these beds include *Pseudomonotis subcircularis* (Gabb), an "extreme local variety" of "*Halobia lommeli?*," and *Arniotites vancouverensis* Whiteaves.

It is probable that the same horizon is present in the Vancouver series

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[48] George M. Dawson: Report on the Queen Charlotte Islands. Geol. Survey of Canada. Report of progress for 1878-1879, 1880, pp. 48B, 55B, 58B, 59B, 61B, 62B, 63B, 82B.

[49] George M. Dawson: Report on the Queen Charlotte Islands. Geol. Survey of Canada. Report of progress for 1878-1879, 1880, pp. 48B, 59B, 62B.

[50] J. D. McKenzie: South-central Graham Island, British Columbia. Summary report of the Geological Survey, Department of Mines [Canada], for 1913, pp. 40-42.

[51] George M. Dawson: Report on the Queen Charlotte Islands. Geol. Survey of Canada. Report of progress for 1878-1879, 1880, p. 82B.

at the north end of Vancouver Island, where Dawson has described[52] flaggy limestones, calcareous argillites, black flinty argillites, etcetera, which overlie a massive limestone and are overlain by sandstones, above which are volcanic beds. The section is closely similar to that of the Queen Charlotte Islands. The fossils from the flaggy limestones and argillites were described[53] by Whiteaves as including the following species:

Halobia (Daonella) lommeli ? (extreme local variety).
Arcestes gabbi Meek.
Arniotites vancouverensis Whiteaves.
Arniotites sp.
Arniotites or *Celtites* sp.

It has been generally assumed that these fossils are Middle Triassic, which would undoubtedly be the case, at least for the *Daonella* and the *Arcestes,* if the species have been correctly determined. It was the opinion of Frech[54] that the ammonites described as *Arniotites* are also indicative of Middle Triassic age, "*Arniotites vancouverensis*" probably being a *Celtites,* "*Arniotites* or *Celtites* sp." being a *Celtites* related to *C. epolense* Mojsisovics, and "*Arniotites* sp." being a *Ceratites* related to *C. japonicus* Mojsisovics.

The writer doubts whether any of these fossils from Vancouver Island are Middle Triassic and believes that it is highly probable that they are all Upper Triassic. The reasons for this belief are as follows: Whiteaves expressed considerable doubt concerning the identification of *Halobia (Daonella) lommeli* and considered that[55] the Vancouver Island specimens "may possibly represent an extreme local variety of this species." He recognized the same "extreme local variety" as occurring in association with *Pseudomonotis subcircularis* in the flaggy limestones and argillites of the Queen Charlotte Islands. This form is probably identical with neither *Daonella lommeli* Wissman of Europe nor *Daonella dubia* Gabb of Nevada, but is more likely an Upper Triassic species of *Halobia.* The fossils identified by Whiteaves as *Arcestes gabbi* Meek have been neither described nor figured and may possibly belong to some of the Upper Triassic species of *Arcestes* which had not been recognized in

[52] George M. Dawson: Report on a geological examination of the northern part of Vancouver Island and adjacent coasts. Geological and Natural History Survey of Canada, vol. ii, new series, 1886, pp. 9B, 26B, 73B, 76B, 83B, 89B.

[53] J. F. Whiteaves: On some fossils from the Triassic rocks of British Columbia. Contributions to Canadian paleontology, vol. 1, pt. ii, No. 3, 1889, pp. 134, 141, 146-147, pl. 19, figs. 3, 4.

[54] Fritz Frech: Die zircumpacifische Trias. Lethæa geognostica. Teil ii, Bd. 1, 1908, pp. 490-491.

[55] J. F. Whiteaves: On some fossils from the Triassic rocks of British Columbia. Contributions to Canadian paleontology, vol. 1, pt. ii, No. 3, 1889, p. 134.

America at the time Whiteaves made his studies. *Arniotites vancouverensis* was described by Whiteaves from the argillites of Queen Charlotte Islands that contain *Pseudomonotis subcircularis.* This species has been reported[56] also, together with *Pseudomonotis subcircularis,* in the Parson Bay group of Harbledown Island. It probably occurs also in the argillites of the Cultus formation[57] on the west slope of the Cascades, where it is associated with *Aulacoceras ?* cf. *carlottense* Whiteaves. The latter genus, according to Mojsisovics, is known only in the Upper Triassic. The fossil from Robson Island, described by Whiteaves[58] as *Arniotites* sp., is closely related, according to Frech,[59] to *Ceratites japonicus* Mojsisovics of the Triassic of Japan. Although the latter species has been referred[60] to the Ladinic, it occurs[61] in beds that apparently overlie those containing *Pseudomonotis ochotica.* It should also be noted that *Arniotites* probably occurs in Alaska (see pages 695, 712) in the upper part of the McCarthy formation.

The Pseudomonotis horizon of Alaska is probably represented on the islands east of Vancouver Island by the Parson Bay group,[62] which consists of "shales, argillites, impure limestones, calcareous sandstones and quartzites," which contain *Pseudomonotis subcircularis, Halobia, Natica (?),* and *Arniotites vancouverensis,* and which rest on the lavas, breccias, and tuffs described as the Valdes group.

These rocks may be correlated also with the argillites of the Cultus formation,[63] which is exposed near the western base of the Cascade Range and which contains *Arniotites vancouverensis* Whiteaves (?) and *Aulacoceras (?)* cf. *carlottense* Whiteaves.

The argillites of Whipsaw Creek, near the headwaters of the Similkameen, on the crest of the Cascades, which were described by Dawson[64] as

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[56] J. Austen Bancroft: Geology of the coasts and islands between the Strait of Georgia and Queen Charlotte Sound, British Columbia. Geol. Survey of Canada, Memoir 23 (No. 1188), 1913, pp. 75-76, pl. ix (b).

[57] R. A. Daly: Geology of the North American Cordillera at the Forty-ninth parallel. Geol. Survey of Canada, Memoir 38, pt. 1, 1912, pp. 516-517.

[58] J. F. Whiteaves: On some fossils from the Triassic rocks of British Columbia. Contributions to Canadian paleontology, vol. 1, pt. ii, No. 3, 1889, p. 147, pl. 19, fig. 3.

[59] Fritz Frech: Die zircumpacifische Trias. Lethæa geognostica, Teil ii, Bd. 1, 1908, p. 490.

[60] Fritz Noetling: Die asiatische Trias. Lethæa geognostische, Teil ii, Bd. 1, Lieferung 2, 1905, pp. 195-196, 220.

[61] Edmund von Mojsisovics: Ueber einige japanische Triasfossilien. Beiträge zur Palæontologie Osterreich-Ungarns. Bd. vii, 1889, pp. 163-178.

[62] J. Austen Bancroft: Geology of the coasts and islands between the Strait of Georgia and Queen Charlotte Sound, British Columbia. Geological Survey of Canada, Memoir 23 (No. 1188), 1913, pp. 75-77.

[63] R. A. Daly: Geology of the North American Cordillera at the Forty-ninth parallel. Geol. Survey of Canada, Memoir 38, pt. 1, 1912, pp. 516-517.

[64] George M. Dawson: Preliminary report on the physical and geological features of the southern portion of the interior of British Columbia. Geol. Survey of Canada. Report of progress for 1877-1878, pp. 66B, 67B.

occurring in a syncline and as underlain by volcanic rocks that were correlated with those of the Nicola series and which contain fossils that Whiteaves doubtfully referred[65] to *Pseudomonotis subcircularis,* possibly also belong at this horizon. They should, however, not be confused with the Middle Triassic beds (see page 705) of Thompson River and of Nicola Lake (?) with which Dawson correlated[66] them.

Beds containing *Pseudomonotis subcircularis* occur in a more or less continuous belt along the eastern front of the Rocky Mountains of British Columbia and Yukon. The known localities are on upper Pine River;[67] on Peace River, about 27 miles below the juncture of Finlay and Parsnip rivers, where the rocks have been described by Selwyn[68] and by McConnell[69] as consisting of calcareous shales and impure limestones; and near the headwaters of Stewart River, where, according to Keele, they include[70] impure limestones, argillites, and quartzites, with *Pseudomonotis subcircularis, "Halobia lommeli,"* and *Arpadites (?).*

The generally accepted assignment of the Pseudomonotis-bearing beds of Alaska to the horizon of the Upper Noric of Europe and Asia is based on the close relationship of the Alaskan fossil identified as *Pseudomonotis subcircularis* (Gabb) with *Pseudomonotis ochotica* (Keyserling), which is the characteristic fossil of the boreal Upper Noric beds of Asia. This relationship was long ago shown by Teller[71] and by Mojsisovics.[72] Specimens from Cold Bay, on the Alaska Peninsula, have more recently been examined by Frech,[73] who has identified them as including both the typical form of *Pseudomonotis ocholica* (Keyserling) and also *Pseudomonotis ochotica* var. *sparicostata* Teller. Further confirmation of this correlation is found in the general similarity of the Alaskan Upper Triassic section as a whole to that of California and other regions.

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[65] J. F. Whiteaves: On some fossils from the Triassic rocks of British Columbia. Contributions to Canadian paleontology, vol. 1, pt. ii, No. 3, pp. 127-132.

[66] George M. Dawson: Report on the area of the Kamloops map-sheet, British Columbia. Geol. Survey of Canada, Ann. Rept. (new series), vol. ii, 1896, pp. 50B-137B.

[67] J. F. Whiteaves: Notes on some Jurassic fossils collected by G. M. Dawson in the Coast Range of British Columbia. Geol. Survey of Canada. Report of progress for 1876-1877, p. 158.

[68] Alfred R. C. Selwyn: Report on exploration in British Columbia. Geol. Survey of Canada. Report of progress for 1875-1876, pp. 75, 80, 97.

[69] R. G. McConnell: Report on an exploration of the Finlay and Omenica rivers. Geol. Survey of Canada. Ann. Rept. for 1894, vol. vii (new series), 1896, pp. 32C, 35C.

[70] J. Keele: Report on the upper Stewart River region, Yukon. Geol. Survey of Canada, Ann. Rept. (new series), vol. xvi, 1906, pp. 14C, 15C, 17C.

[71] Friedrick Teller: Die Pelecypod-Fauna von Werchojansk in Ostsiberien. Mem. Acad. Imp. Sci., St. Petersburg, 7th ser., vol. 33, No. 6, 1886, pp. 110, 113, 115.

[72] Edmund von Mojsisovics: Arktische Triasfaunen. Mem. Acad. Imp. Sci., St. Petersburg, 7th ser., vol. 33, No. 6, 1886, p. 147.

[73] Fritz Frech: Die zircumpacifische Trias. Lethæa geognostische, Teil ii, Bd. 1, 1908, p. 489, pl. 68, fig. 3*a*.

'eon.			Alaska.		
pine.			Southwestern Alaska.	Southeastern Alaska.	Yukon Valley and Northern Alaska.
tone tt.	Pseudo-monotis ochotica in the Crimea.	Pse of an	Calcareous shale with Pseudomonotis subcircularis.	Upper limestone at Hamilton Bay with Pseudomonotis.	Pseudomonotis zone of the Yukon River and Arctic Mountains.
			Cherts (fossils not known).		
			Coral limestone of Iliamna Lake.	? Limestone of Gravina Island (corals).	
s with Tropites ullatus.		H		Limestones of Herring and Hamilton Bays, with Halobia cf. superba, etc.	Limestone of Yukon, Firth, and Canning Rivers, with Halobia cf. superba, Clionites, brachiopods, etc.
th Trachyceras oides.					
s with Trachy-s aon.		D		Limestone near Hamilton Bay with Dawsonites (not found in place).	
's with Trachy-rchelaus.					
in beds with eras reitzii.		Ce A			
tones of Han g, Bakony, and Schrey Alps, Ceratites tri-sus.		Beds of Ussuri Bay in eastern			Slates of Brooks Mountain with Daonella and Ceratites (Gymnotoceras).
odosus beds in uth Alps.					
lf of Ismid, in Minor.					
nbites beds in Albania.		C			
pil beds with tes cassianus.					
eds with Pseu-onotis clarai.		Prop of sou			

Interregional Correlation of the Triassic (after Prof. James Perrin Smith, except for Alaska)

	Series.*	Stage.*	Substage.*	Interregional zone.	Mediterranean region. German.	Mediterranean region. Alpine.	Arctic-Pacific region.	Oriental region. Himalaya.	Oriental region. Salt Range.	American region. California.	American region. Nevada.	American region. Idaho.	American region. British Columbia.	Alaska. Chitina Valley.	Alaska. Southwestern Alaska.	Alaska. Southeastern Alaska.	Alaska. Yukon Valley and Northern Alaska.
Upper Triassic.	Bajuvaric.	Rhætic.			Rhætic.												
		Noric.		Pseudomonotis ochotica.	Keuper.	Noric limestone of Hallstatt. Pseudomonotis ochotica in the Crimea.	Pseudomonotis ochotica slates of northern Siberia, Japan, and Indian Ocean.	Monotis beds. Limestones with Halorites.		Brock shales. Slates carrying Pseudomonotis subcircularis, Rhabdoceras and Halorites. Hosselkus limestone. Spiriferina beds. Coral zone.	Star Peak formation. Pseudomonotis-bearing slates, with Rhabdoceras and Placites.		Pseudomonotis-bearing slates.	McCarthy formation (shales with chert in lower part). Contains Pseudomonotis subcircularis. Nizina limestone? (in part?)	Calcareous shale with Pseudomonotis subcircularis. Cherts (fossils not known). Coral limestone of Iliamna Lake.	Upper limestone at Hamilton Bay with Pseudomonotis. ? Limestone of Gravina Island (corals).	Pseudomonotis zone of the Yukon River and Arctic Mountains.
	Tirolic.	Karnic.	Tuvalic.	Tropites subbullatus.		Sandling beds with Tropites subbullatus.	Halobia slates of Eureka Sound and Spitzbergen.	Halobia beds. Tropites limestones.		Zone of Tropites subbullatus. Juvavites beds. Trachyceras beds. Halobia superba zone.	Limestones without characteristic fossils			Nizina limestone (in part?) Chitistone limestone (with Halobia cf. superba, Tropites, Juvavites, Arcestes, etc.).		Limestones of Herring and Hamilton Bays, with Halobia cf. superba, etc.	Limestone of Yukon, Firth, and Canning Rivers, with Halobia cf. superba, Clionites, brachiopods, etc.
			Julic.			Raibl beds with Trachyceras aonoides.											
			Cordevolic.			Cassian beds with Trachyceras aon.	Dawsonites slates of Bear Island.	Daonella beds. Beds with Trachyceras tibeticum.		Slates with Halobia cf. rugosa.			Dawsonites zone.			Limestone near Hamilton Bay with Dawsonites (not found in place).	
		Ladinic.	Longobardian.	Daonella lommeli.		Wengen beds with Trachyceras archelaus.		Beds with Trachyceras archelaus and Daonella lommeli.		Pit shale. Shales and tuffs without determinable fossils.							
Middle Triassic.	Upper Muschelkalk.		Fassanic.		Upper Muschelkalk.	Buchenstein beds with Trachyceras reitzii.	Ceratite slates of Japan with Anakites and Danubites.	Beds with Trachyceras cautleyi.			Daonella zone in West Humboldt Range. Daonella dubia zone with Ceratites trinodosus.		Daonella zone.				
	Middle Muschelkalk. Dinaric.	Anisic.	Bosnian.	Ceratites trinodosus.	Middle Muschelkalk.	Reifling limestone. Limestones of Han Bulog, Bakony, and the Schrey Alps, with Ceratites trinodosus.	Beds of Ussuri Bay in eastern Siberia with Monophyllites sichoticus. Mengilach beds. (?) Daonella limestones of Spitzbergen.	Upper Muschelkalk with Ptychites rugifer and Ceratites trinodosus.		Clay and siliceous shales with Nevadites cf. whitneyi and Ceratites cf. humboldtensis.							Slates of Brooks Mountain with Daonella and Ceratites (Gymnotoceras).
	Lower Muschelkalk.	Hydaspic.	Balatonic.		Lower Muschelkalk with Hungarites strombecki.	Ceratites binodosus beds in the South Alps. Beds on Gulf of Ismid, in Asia Minor.		Lower Muschelkalk.		Ceratite-bearing limestones of Inyo Range. Black limestones with Parapopanoceras, Xenodiscus, Acrochordiceras, and Hungarites.							
Lower Triassic.	Scythic.	Jakutic.		Columbites fauna.	Buntsandstein.	Werfen beds. Columbites beds in Albania.	Olenek beds of northern Siberia.	Stephanites beds.	Ceratite beds. Upper Ceratite limestone. Ceratite sandstone.	Calcareous slates without fossils.		Beds of Aspen Mountains. Columbites zone.					
				Tirolites cassianus in Mediterranean region and Idaho.		Campil beds with Tirolites cassianus.		Hedenstroemia and Flemingites beds.	Ceratite marl.			Tirolites zone.					
		Brahmanic	Gangetic.	Meekoceras fauna in Siberia, India, California, and Idaho.		Seis beds with Pseudomonotis clarai.	Proptychites beds of Ussuri Bay, in southern Siberia. Posidonomya limestones of Spitzbergen.	Meekoceras beds.	Lower Ceratite limestone.	Meekoceras zone of Inyo County, Cal., with Meekoceras gracilitatis, Ussuria, Pseudosageceras, Inyoites, Owenites, Nannites.		Meekoceras zone.					
			Gandaric.					Otoceras beds.									

*These series, stage, and substage terms have not been adopted by the United States Geological Survey.

Geologic History of Alaska in Triassic Time

The youngest known Paleozoic rocks of Alaska are the Permian (?) limestones, which carry a fauna closely allied to that of the Artinskian of Russia. The wide distribution of this limestone indicates that there was a period of profound submergence in late Paleozoic time. The Artinskian sea probably extended over the larger part, if not all, of Alaska.

Since Lower Triassic rocks have not been recognized in Alaska, it is believed that the end of Paleozoic time was marked by a wide-spread emergence which continued until the beginning of the Upper Triassic.

The Permian or early Triassic lavas of the Pacific coastal belt, which are represented by the Nikolai greenstone of the Chitina Valley, the basic lavas and tuffs of the upper Susitna Valley, the ellipsoidal lavas of Kenai Peninsula and Kodiak Island, the greenstones of the Iliamna-Clark Lake district, and the ellipsoidal lavas of Hamilton Bay (and which may be represented by the Orca greenstones of Prince William Sound and by some of the greenstones of southeastern Alaska), indicate a period of intense, wide-spread, and probably long-continued volcanic activity that probably occurred in early Triassic time. These volcanic rocks, as far as known, are not intercalated with marine sediments and presumably were poured out on land during the Permian or early Triassic period of emergence. The non-fossiliferous sedimentary rocks which are intercalated with the Orca greenstones are, in the writer's opinion, not marine. The volcanic activity of this period apparently extended throughout the entire region south of the Alaska Range, from the Alaska Peninsula eastward and southward into British Columbia. Volcanic rocks of this date are not known north of the Alaska Range and probably were never present there, although their absence may be due to post-Triassic erosion. This sharp limitation of the distribution of these rocks along the present line of the major mountain axis of Alaska is very significant and, in the writer's opinion, clearly indicates that this line marked the northern limit of the supposed early Triassic volcanic activity.

Middle Triassic time was probably a period of emergence in Alaska, for Middle Triassic rocks are known only in Seward Peninsula.

The Upper Triassic was a time of submergence, when limestone-forming seas swept over large Alaskan areas. The initial Upper Triassic submergence was probably in Karnic time, when limestones were deposited throughout the greater part, if not all, of the present Pacific Mountain region, being known along the Pacific coast from southeastern Alaska to Cook Inlet and in the Copper and the Susitna valleys. These limestones locally attain a thickness of at least 3,000 feet and, in general, are not in-

terbedded with strata of other kinds. The fauna of these supposed Karnic beds of southern Alaska is of the Mediterranean type and probably indicate warm-water conditions. The transgression of the Karnic sea was probably from the south. Limestones that presumably were synchronous with these, but which possibly were laid down in different basins that may have maintained a connection with the boreal sea, are known in the present sites of the Rocky and the Arctic Mountains or on the upper Yukon and on the eastern part of the Arctic slope.

The sea probably receded in Lower Noric time from the greater part of Alaska, for rocks of supposed Lower Noric age are definitely known only in the vicinity of Iliamna Lake, where they are represented by limestone containing a warm-water coral-reef fauna.

The Upper Noric was the time of a great transgression of the sea, when the greater part, if not all, of Alaska was submerged. The supposed Upper Noric rocks consist of shales, impure limestones, and cherts, with locally some volcanic beds. They contain a boreal fauna that is allied to that of northern Asia and that possibly indicates a cold-water sea in contrast with the preceding warm-water seas of Karnic and of Lower Noric times. This marked difference in faunal conditions, together with the general absence of Lower Noric beds between the Upper Noric and the underlying Karnic strata and with the strong suggestions of an unconformity at the base of the Upper Noric beds (see pages 695, 701, 711), indicates that there was an important recession of the sea at the end of Karnic time. The invading Upper Noric sea probably came in from the northwest.

There was a general emergence of the land at the end of Noric time, when the sea probably retired beyond the present continental limits. Rhætic and early Lias deposits are not known in Alaska, and it is believed that the continent stood above sealevel from the end of Noric until late Lias (Toarcian) time. An important period of folding followed the deposition of the local Upper Triassic strata, but the date of this folding has not been determined more closely than post-Triassic and pre-Upper Jurassic. The beginning of the local record in Jurassic (probably Upper Lias or Toarcian) time was marked by a moderate submergence, accompanied or followed by intense volcanic activity along the present Pacific seaboard.

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